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THE INFLUENCE OF MATERIAL TYPES ON TWIST ANGLES AND TORSION STABILITY OF A COMPOSITE SHAFT

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Original scientific paper

The advantages of composite materials over the conventional ones include the ability to vary their properties in order to ensure the best combination for each application. This is achieved through selection of their constituent materials, quantities, distribution and fibre orientation angle. In some cases, the best results can be achieved by using a combination of composite and traditional metal materials. This paper analyses shafts made from a combination of aluminium and different composite materials – carbon fibre/epoxy, glass fibre/epoxy, and aramid fibre/epoxy. The influence of these materials on twist angle values and critical torques that impair the shaft stability has also been discussed. Finally, an experimental analysis of the shaft that exhibited the best properties (carbon fibres/epoxy) has been performed.

Keywords: *aramid fibre, carbon fibre, glass fibre, hybrid aluminium/composite shaft*

Utjecaj vrste materijala na kutove uvijanja i uvojnu stabilnost kompozitnog kardanskog vratila

Izvorni znanstveni članak

Prednost primjene kompozitnih materijala, u odnosu na konvencionalne materijale, ogleda se u mogućnosti širokog variranja praktično svih svojstava materijala od kojih su sastavljeni, što se postiže putem izbora sastavnih komponenata, njihove količine, rasporeda i orijentacije u okviru materijala, a s ciljem da se iskoriste njihova najbolja svojstva. U nekim slučajevima najbolji rezultati mogu biti postignuti uporabom kombinacije kompozita i tradicionalnih metalnih materijala. U radu su analizirana vratila dobivena kombinacijom aluminija s različitim kompozitnim materijalima – karbonska vlakna/epoksi smola, staklena vlakna/epoksi smola, aramidna vlakna/epoksi smola. Razmatran je njihov utjecaj na vrijednosti kutova uvijanja i kritične vrijednosti momenta uvijanja koje dovode do gubitka stabilnosti vratila. Provedena je i eksperimentalna analiza vratila koje je pokazalo najbolja svojstva (karbonska vlakna/epoksi smola).

Ključne riječi: *aramidna vlakna, karbonska vlakna, kombinirana aluminij/kompozitna vratila, staklena vlakna*

1 Introduction

In addition to new design and manufacturing technologies, modern mechanical constructions involve application of new materials with higher hardness and strength but lower density and mass. In such circumstances, the use of composite materials is very advantageous because their properties are improved compared to the known metals and alloys.

Composites are made by combining two or more materials. These materials form a composite with controlled properties and more desirable characteristics. Composite materials have significantly better properties than their constituents do. They have small masses, an excellent mass to strength ratio and they are suitable for various applications.

With designers being aware of the advantages of composites in mechanical industry, composite materials are being increasingly used instead of traditional steel elements. At first, composites were used mainly in aircraft industry, but today fibre strengthened composites are used to manufacture structural elements in many different industries. They are penetrating and conquering new markets, therefore the number of composite materials and possibilities of their application are constantly increasing.

The advantages of composite materials over metals include the following:

- four to six times higher tensile strength compared to steel or aluminium,
- increased impact resistance,
- increased fatigue resistance,
- better vibration resistance compared to metals,
- high corrosion resistance and resistance to temperature changes,
- a long life cycle,
- they eliminate the need for joints, which are necessary when metal parts are used, etc.

Properties of composite materials (stiffness, resistance, thermal expansion, etc.) can vary depending on the type of the applied material, quantity, fibre orientation angle, etc.

Composite industry worldwide constantly invests in technologies for manufacturing of composites. Nowadays, composite materials are used in manufacturing of drive shafts in automotive industry.

In cases of transmission shafts, the best results can be achieved using a combination of composite and traditional metal materials. Many authors have analysed static and dynamic characteristic of these types of shafts.

In paper [1], Badie et al. analysed the effects of fibre orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength and failure modes of composite tubes using both finite element method (FEM) analysis and experimental techniques.

In his paper [2], Naveen Rastogi, presented a design for drive shaft used in automobiles. He considered two important aspects of driveshaft design: a design of composite shaft tube and a design of the joint between the yoke and the shaft tube. He also discussed the obtained results.

Hybrid shafts made of aluminium combined with glass fibres were analysed in [3]. Static torsion capability was studied experimentally. The results show that the static torque capacity for the winding angle of 45° is higher than 90°.

The FEM approach was used to analyse the influence of the type of material (glass, carbon) and orientation angles on the natural frequency and the buckling torque [4].

The torsional stability of a composite drive shaft under torsion was studied by Shokrieh et al. [5] using different fibre orientations and the stacking sequences.

The paper [6] gives a new method to manufacture a one-piece aluminium/composite drive shaft for rear-drive vehicles. Composite material made of several layers is applied on the inside walls of the aluminium tube in order to protect it from impact or corrosion damage.

2 Basic theoretical settings of the shell shaped finite element

Shell is a thin surface structure of general shape. Shells are frequently used in technical practice today. Depending on their thickness, they are classified as thin, medium thick or very thick shells.

With shells, it can be rather difficult to calculate the stress state, deformation field, response at different loading conditions, buckling, etc. For that reason, different hypotheses and shell theories have been developed and many elements with different degrees of freedom, basic parameters, interpolations of displacement and approximations of the shell geometry have been formulated. However, none of these elements can be considered universal or superior. Shells continue to be studied and improved.

Basic parameters used to describe the shell geometry are the middle surface area, the thickness and the normal of the shell.

The middle surface area is defined as [7]:

$$f(x, y, z) = 0. \tag{1}$$

In relation to the xyz coordinate system and it represents a set of points M_0 as shown in Fig. 1. The vector perpendicular to the plane $\boldsymbol{g}_n$ is determined as a gradient to the middle surface area [7]:

$$\boldsymbol{g}_n = \nabla f, \tag{2}$$

with components:

$$\boldsymbol{g}_{nx} = \frac{\partial f}{\partial x}, \boldsymbol{g}_{ny} = \frac{\partial f}{\partial y}, \boldsymbol{g}_{nz} = \frac{\partial f}{\partial z}. \tag{3}$$

The equation of the normal vector is [7]:

$$n = \frac{\boldsymbol{g}_n}{\|\boldsymbol{g}_n\|} = \frac{\nabla f}{\|\nabla f\|}. \tag{4}$$

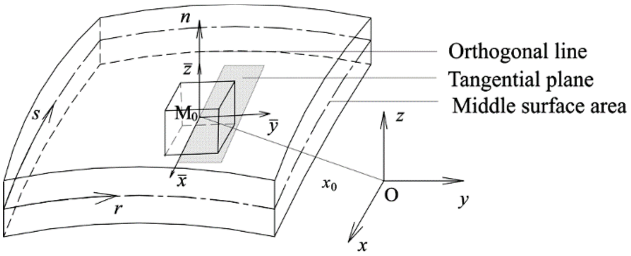

Figure 1 Geometry of the shell

A tangential plane can be placed at the point M_0, in the middle surface area. The vector is perpendicular to the plane. The local coordinate system $\bar{x}, \bar{y}, \bar{z}$, is also placed at the point M_0. The $\bar{x}$ and $\bar{y}$ axes lie in the tangential plane, while the $\bar{z}$ axis is in the direction of the normal $\boldsymbol{n}$. The shell thickness h is defined in the direction of the normal, while the middle surface area cuts the thickness into two halves.

For practical analysis of shells, it is necessary to determine deformations at material points [7, 8]. This can be done if the displacement field is known:

$$\boldsymbol{u} = \boldsymbol{u}(x, y, z). \tag{5}$$

The field is known if the functions are known:

$$\boldsymbol{u}_0 = \boldsymbol{u}_0(x, y, z). \tag{6}$$

$$\boldsymbol{\varphi} = \boldsymbol{\varphi}(x, y, z). \tag{7}$$

Each of the Eqs. (6) and (7) has three corresponding scalar equations. These functions can be expressed in the natural coordinates as follows:

$$\boldsymbol{u}_0 = \boldsymbol{u}_0(r, s). \tag{8}$$

$$\boldsymbol{\varphi} = \boldsymbol{\varphi}(r, s). \tag{9}$$

In view of kinematics of shell deformation, it is important to assume that the normal stress tension in the direction perpendicular to the shell equals zero [7]:

$$\sigma_{\bar{z}\bar{z}} = 0. \tag{10}$$

Under the effect of the normal stresses $\bar{\sigma}_{xx}$ and $\bar{\sigma}_{yy}$ in the tangential plane, material deforms in the direction of the normal, which is determined as:

$$\bar{\varepsilon}_{zz} = -\frac{\nu}{E}\left(\bar{\sigma}_{xx} + \bar{\sigma}_{yy}\right). \tag{11}$$

2.1 Orthotropic multiplayer shell

In multiple layer shells (Fig. 2), high stiffness of the shell construction can typically be achieved with adequate fibre orientations and material directions and with low thickness. Basic hypotheses applied to cinematic deformation of an isotropic shell can also be applied to orthotropic ones.

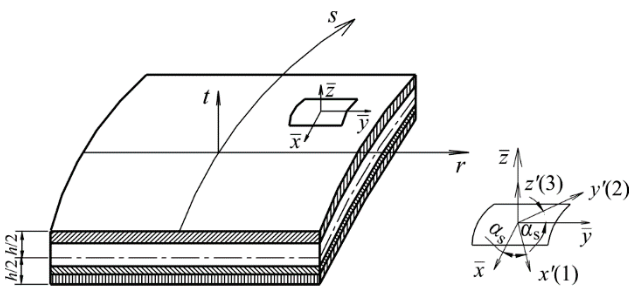

Figure 2 Multiple layer shells

All values are calculated layer by layer, by formulating finite elements of the multiple layer shell [8]. In this case, the basic values such as displacement and deformation are calculated in the material coordinate system x', y', z'.

We get:

$$\boldsymbol{\varepsilon}' = \boldsymbol{T}'^{\varepsilon}\overline{\boldsymbol{\varepsilon}} = \boldsymbol{T}'^{\varepsilon}\boldsymbol{T}^{\varepsilon}\boldsymbol{\varepsilon} = \overline{\boldsymbol{T}}^{\varepsilon}\boldsymbol{\varepsilon}, \tag{12}$$

where $\overline{\boldsymbol{\varepsilon}}$ and $\boldsymbol{\varepsilon}'$ are deformations in the system $\overline{x}, \overline{y}, \overline{z}$ and x', y', z', respectively, and $\boldsymbol{T}'^{\varepsilon}$ is the transformation matrix.

The stiffness matrix of the layer s is [8]:

$$\boldsymbol{K}^{\mathrm{s}} = \int_{V^{\mathrm{s}}} \overline{\boldsymbol{p}}^{\mathrm{sT}}\overline{\boldsymbol{D}}^{\mathrm{s}}\overline{\boldsymbol{p}}^{\mathrm{s}}\mathrm{d}V, \tag{13}$$

here, $\overline{\boldsymbol{p}}^{\mathrm{s}}$ is the interpolation matrix and $\overline{\boldsymbol{D}}^{\mathrm{s}}$ is the tensile matrix of the layer, given in material coordinate system x', y', z'. In practice, numerical integration is performed by the layer volume V^{s}, while the stiffness matrix $\boldsymbol{K}$ is given as the sum of layer stiffnesses [8]:

$$\boldsymbol{K} = \sum_{\mathrm{s}} \boldsymbol{K}^{\mathrm{s}}. \tag{14}$$

Stress at a material point in a layer s is given as:

$$\boldsymbol{\sigma}' = \overline{\boldsymbol{D}}^{\mathrm{s}}\boldsymbol{\varepsilon}'. \tag{15}$$

where the stress σ' corresponds to the coordinate system x', y', z'. The force vector at nodes, $\boldsymbol{F}^{u}$, has the following form [8]:

$$\boldsymbol{F}^{u} = \sum_{\mathrm{s}} \int_{V^{\mathrm{s}}} \overline{\boldsymbol{p}}^{\mathrm{sT}}\boldsymbol{\sigma}'\mathrm{d}V. \tag{16}$$

Hollow shafts with small wall thickness, like composite shafts, are usually analysed using shell elements. In case of laminated shafts, analysis is performed by application of orthotropic multi-layer shells [7, 8, 9, 21], etc.

3 Numerical analysis of the hybrid Al/composite cardan shafts

This paper studies the shaft of a truck TURBO ZETA 85.14B. It considers a possibility to use one shaft made of aluminium and composite materials instead of two steel cardan shafts, while the basic demands concerning the load carrying capacity remain satisfied.

The analysed shaft [9] has the following dimensions: the length of the shaft is 1,35 m, its mean radius is 0,041 m, while the wall thickness of the ring shaped cross section of the shaft is 0,003 m. The shaft was tested for the maximum value of the static torque of 5000 N·m.

A combination of aluminium and composite material has been shown to give good results [1, 3], etc. The shafts analysed here are formed combining aluminium and carbon fibres/epoxy composites, glass fibres/epoxy composites and aramid fibres/epoxy composites. Tab. 1 shows the basic characteristics of this composite material.

Table 1 Basic characteristics of the composite material

Material	E_1 (GPa)	E_2 (GPa)	G_{23} (GPa)	G_{12} (GPa)	v	ρ (kg/m^3)	t_s (mm)
Carbon fibres/epoxy composite (USN150)	131,60	8,20	3,50	4,50	0,281	1550	0,125
Glass fibres/epoxy composite (UGN150)	43,30	14,70	3,50	4,40	0,300	2100	0,125
Aramid fibres/epoxy composite (UKN100)	81,80	5,10	1,82	1,51	0,3100	1380	0,125

In Tab. 1, the following notation is used: E_1 – longitudinal modulus; E_2 – transverse modulus; G_{12}, G_{23} – shear modulus; v – Poisson's ratio; ρ – density; t_s – composite layer thickness.

Characteristics of the aluminium tube used in combination with the composite material in hybrid aluminium/composite shafts are given in Tab. 2.

Table 2 Basic characteristics of the aluminium tube

Tensile modulus E	72 GPa
Shear modulus G	27 GPa
Density ρ	2695 kg/m^3
Yielding strength R_e	325 MPa
Shear strength	210 MPa
Thickness aluminium tube	2,5 mm

3.1 Analysis of the shaft twist angles

The analysed shaft was modelled by linear isoparametric square shell finite elements. It was divided into 80 elements in axial and 50 elements in circular direction. The total of 4050 elements was used for modelling. For the numerical analysis, the shaft was fixed at one end while the other was free and under the effect of the torque. The NX Nastran software was used for the analysis.

The composite part of the shaft consists of 8 layers (carbon fibres/epoxy resin, glass fibres/epoxy resin and aramid fibres/epoxy resin) with the fibre orientation angle of ±45°. Since the bonding thickness between the aluminium tube and the composite layer was very small when co-cured under the pressure, perfect bonding between the aluminium tube and the composite layers was assumed for the finite element analysis.

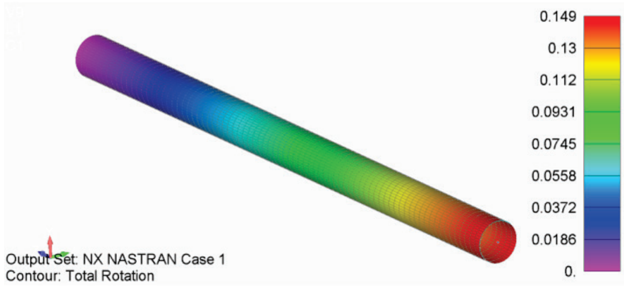

Figure 3 Twist angle for the hybrid Al/carbon fibre/epoxy composite shaft (Al/±45$_{\mathrm{USN,4}}$)

Figs. 3, 4 and 5 show the obtained values of the shaft twist angles for all three types of composite materials under the same conditions (the same shaft dimensions, loads and fibre orientation angles). All these figures (Fig. 6, in particular) show that the lowest values of the twist angles are obtained when the shaft is made of aluminium/carbon fibre/epoxy composite (Al/USN). Combinations of aluminium/glass fibre/epoxy composite (Al/UGN) and aluminium/aramid/epoxy composite (Al/UKN) give similar shaft twist angles, but their values are significantly higher than in the case of carbon fibres.

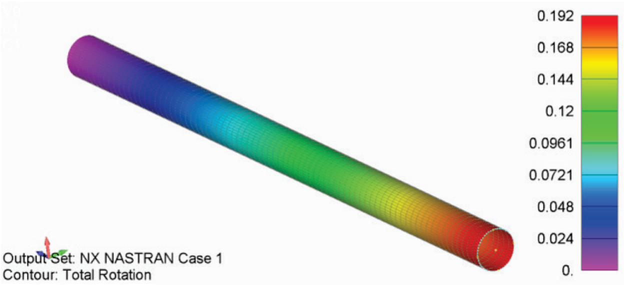

Figure 4 Twist angle for the hybrid Al/glass fibre/epoxy composite shaft (Al/$\pm45_{UGN,4}$)

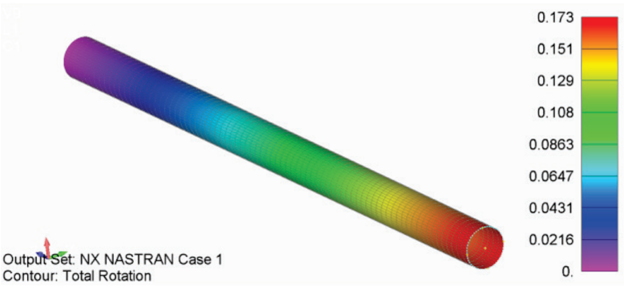

Figure 5 Twist angle for the hybrid Al/aramid fibre/epoxy composite shaft (Al/$\pm45_{UKN,4}$)

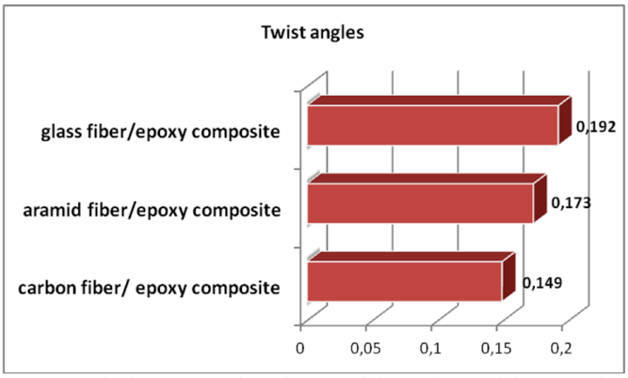

Figure 6 The bar chart of the influence of the shaft material type on the values of the twist angles

Similar results were obtained in papers [1, 11, 12, 13]. The authors analysed shafts made of carbon and glass fibres in [1, 11, 12], and concluded that carbon-epoxy shafts experience smaller angles of twist than the glass-epoxy specimens for the same value of the torque. Although they analysed shafts of various dimensions and with different number of composite layers (but with the orientation angle of ±45°) using different numerical programs (LUSAS, Abaqus, ANSYS, etc.), they all reached the same general conclusions.

The paper [13] analyses stresses and deformations of shafts of made of glass and aramid fibres. It was concluded that aramid fibres exhibit better properties than glass fibres.

3.2 Analysis of shaft stability

Critical buckling torque values that cause instability of the shaft exposed to torsion can be determined numerically by buckling analysis. In fact, the value of the factor λ for the first buckling mode can be determined numerically, while the critical torque can be determined using the following expression:

$$T_{cr} = T_{max} \cdot \lambda, \tag{17}$$

where T_{max} is the value of the maximum torque the shaft is exposed to (in this case 5000 N·m).

The obtained values of the factor λ for the first buckling mode for all the three types of the analysed hybrid shafts are given in Figs. 7, 8 and 9.

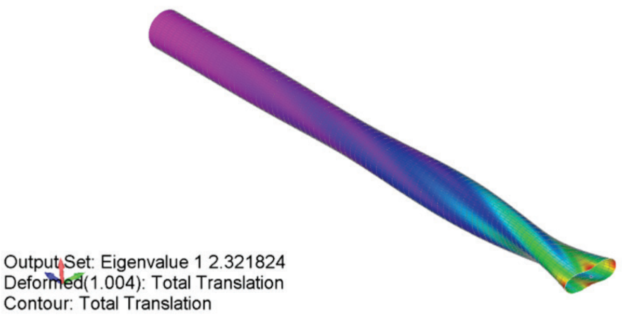

Figure 7 The factor λ for hybrid Al/ carbon/epoxy composite shafts (Al/$\pm45_{USN,4}$)

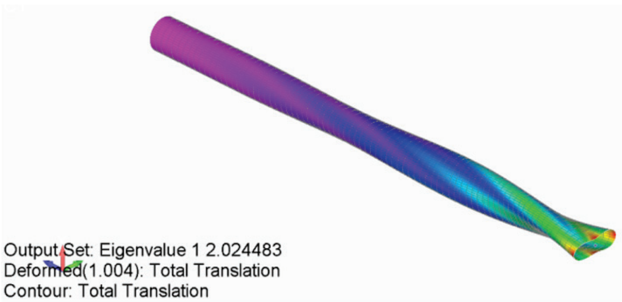

Figure 8 The factor λ for hybrid Al/ glass/epoxy composite shafts (Al/$\pm45_{UGN,4}$)

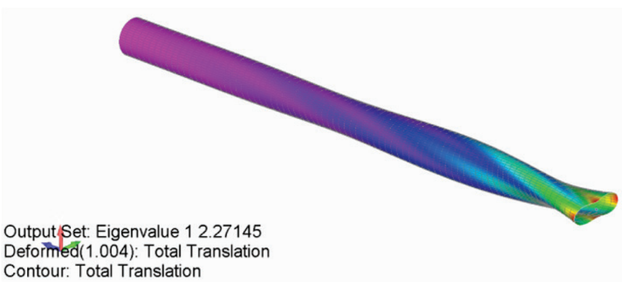

Figure 9 The factor λ for hybrid Al/ aramid/epoxy composite shafts (Al/$\pm45_{UKN,4}$)

The obtained values of the critical buckling torques for the analysed hybrid shafts are given in Tab. 3.

Based on Tab. 3 and especially the bar chart given in Fig. 10, it can be concluded that the critical buckling torque has the highest values for hybrid Al/USN carbon/epoxy composite shafts, slightly lower values for hybrid Al/UKN aramid/epoxy composite shafts, and the lowest values for Al/UGN glass/epoxy composite shafts.

Table 3 Critical buckling torque T_{cr}

Material	Buckling load factor λ	Critical buckling torque (N·m)
Al/[±45$_{USN,8}$] carbon fibre epoxy composite	2,322	11609
Al/[±45$_{UGN,8}$] glass fibre epoxy composite	2,024	10122
Al/[±45$_{UKN,8}$] aramid fibre epoxy composite	2,271	11357

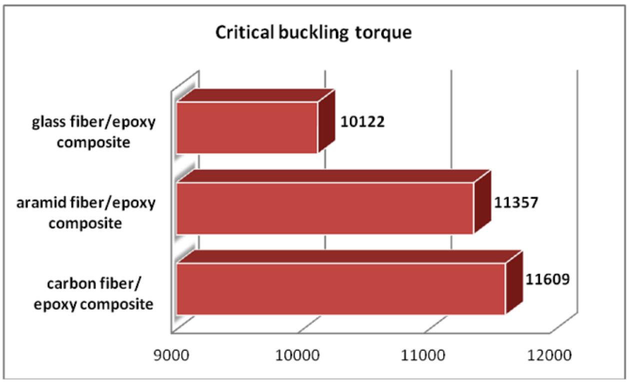

Figure 10 The bar chart of the influence of the material type on the critical buckling torque values

In papers [1, 4, 17], the authors also concluded that the carbon fibre shafts had higher values of T_{cr} compared to glass fibre shafts.

4 Experimental determination of the shaft twist angle

Numerically determined values of the shaft twist angle were verified by experimental analysis performed on the shaft made of aluminium and carbon fibres/epoxy that gave the best numerical results. The composite part of the shaft consisted of 8 layers carbon fibres/epoxy resin, with the fibre orientation angle of ±45°. A scale shaft model with dimensions determined based on the similarity law was used. The real work conditions were simulated. Tab. 4 gives basic dimensions and load values for the real shaft and the shaft model made for experimental analysis.

Table 4 Basic dimensions of the real shaft and the shaft model

Basic characteristics	Real shaft	Model
Outer shaft diameter	85 mm	21,8 mm
Inner shaft diameter	78 mm	20 mm
Composite layer thickness	8 × 0,125 = 1 mm	4 × 0,10 = 0,4 mm
Aluminium tube thickness	2,5 mm	0,65 mm
Shaft length	1350 mm	346 mm
Torque	5000 N·m	85 N·m

The shaft was clamped at one end and twisted at the other end by a torque in the range of 0 ÷ 85 N·m. These values multiplied by the torque increase factor yield the torque values in the range of 0 ÷ 5000 N·m, which equals the loading of a real shaft.

Experimental values of the twist angles were determined in two ways: they were directly measured with a protractor and they were obtained using measuring stripes.

V shaped rosettes with grid axes at the angle of ±45° with respect to the longitudinal axis of the shaft were used for twist angle measuring. Strain gages type 3/120 XY21, produced by HBM (Hottinger Baldwin Messtechnik), were also used (Fig. 11).

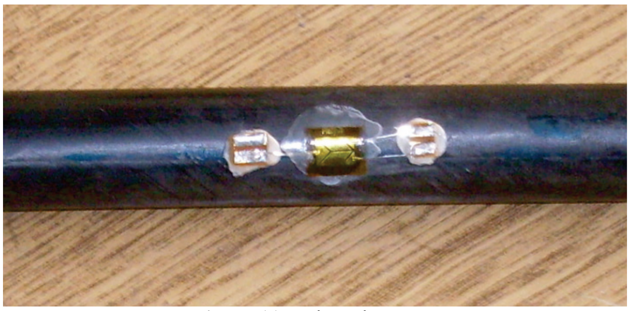

Figure 11 V-shaped rosettes

The strain gages were connected to the multichannel measuring device UPM 60. This is a digital measuring device equipped with a microprocessor. It performs a variety of functions (choice of measuring spot, choice of measuring unit, numerical values display, etc). CATMAN program was used for communication between the UPM 60 and the computer. It also enabled the use and adjustments of the measuring equipment.

Fig. 12 shows the shaft model with glued and connected strain gages, mounted on the testing device.

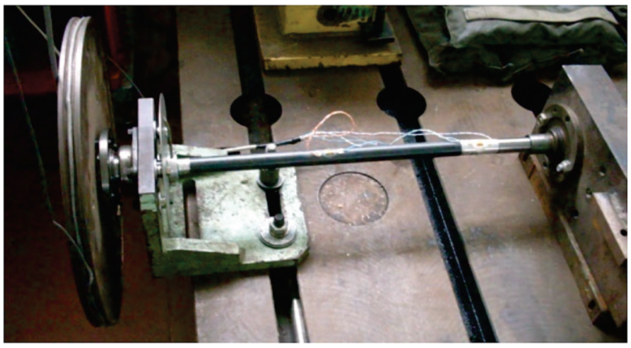

Figure 12 Shaft model ready for testing

The values of the drive shaft twist angles could be determined using the known procedure [9, 20], and based on deformations of the measuring tapes.

In the experimental analysis, the values of the drive shaft twist angles were directly measured with a precise special custom made protractor (Fig. 13).

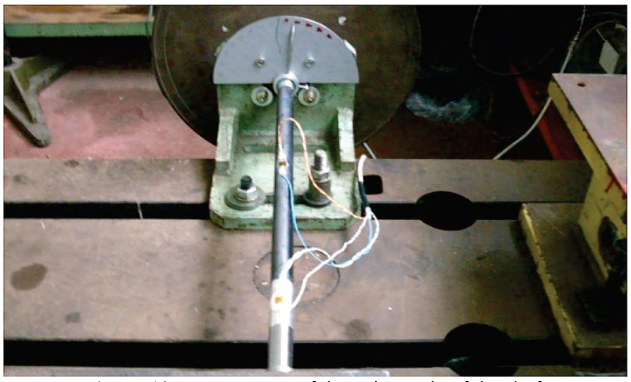

Figure 13 Measurement of the twist angle of the shaft

In order to verify the results, experimental results obtained with measuring stripes (Θ_{exp}) and directly measured values ($\Theta_{exp-mech}$) were compared to the values obtained using the numerical method ($\Theta_{numeric}$). Fig. 14 shows how the drive shaft twist angle depends on the torque.

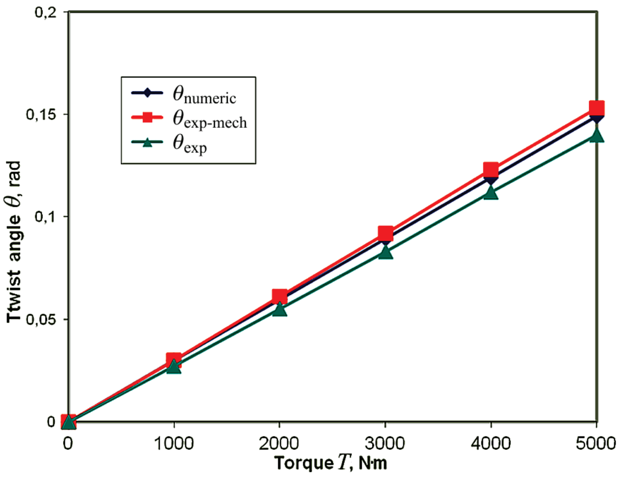

Figure 14 Twist angle as a function of the torque

Based on the values given in the diagram, it can be concluded that numerical results are in good agreement with the experimental results. The difference between these results is insignificant for low values of the torque, but with higher values, the difference increases. However, since the greatest difference does not exceed 3,2 %, it can be concluded that there is an excellent compliance between the results.

A slightly larger difference in results is obtained when the two experimental methods are compared. In that case, the difference varies from 8,5 % to 10 %. The difference between the numerical values and the values obtained using measuring stripes is slightly smaller, and it varies from 6 % to 9 %.

5 Conclusion

The primary objective of this paper was to choose the most suitable material to replace a two-piece steel driveshaft of the truck TURBO ZETA 85.14B with a hybrid driveshaft made of aluminium and composite material, while the basic requirements concerning the load carrying capacity and stability remain satisfied.

Based on the investigations carried out here, the following conclusions have been drawn:

- The numerical analysis showed that smallest deformations (smallest values of the twist angles) were obtained for combined Al/carbon/epoxy shafts. Aramid fibres have slightly worse characteristics, while the worst results were obtained for shafts made from a combination of aluminium and glass fibres.
- Buckling analysis showed that aluminium combined with carbon fibres gave the best results (the highest torque values), aramid fibres showed slightly worse results, while glass fibres yielded the worst results.
- A good agreement between the numerical and experimental results is a confirmation that the developed model of numerical analysis and the applied experimental method were both correct.

Based on the conducted tests it can be concluded that carbon fibres have the best properties concerning strength and stability.

6 References

[1] Badie, M. A.; Mahdi, E.; Hamouda, A. M. S. An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft. // Materials and Design, 32, (2011), pp. 1485-1500.

[2] Rastogi, N. Design of composite driveshafts for automotive applications. // SAE World Congress Detroit, Michigan, March 8÷11, 2004. SAE Paper No. 2004-01-0485.

[3] Mutasher, S. A.; Sahari, B. B.; Hamouda, A. M. S.; Sapuan, S. M. Static torsion capacity of a hybrid aluminum glass fiber composite hollow shaft. // American Journal of Applied Sciences, Special Issue, (2005), pp. 67-71.

[4] Talib, A. R.; Ali, A.; Badie, M. A.; Lah, N. A. C.; Golestaneh, A. F. Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft. // Materials and Design, 31, (2010), pp. 514-521.

[5] Shokrieh, M. M.; Hasani, K.; Lessard, L. B. Shear buckling of a composite drive shaft under torsion. // Composite Structures, 64, (2004), pp. 63-69.

[6] Lee, D. G.; Kim, H.S.; Kim, J.W.; Kim, J. K. Design and manufacture of an automotive hybrid aluminum/composite drive shaft. // Composite Structures, 63, 1(2004), pp. 87-99.

[7] Bathe, K. J. Finite element procedures in engineering analysis, Prentice Hill, 1982.

[8] Kojic, M.; Slavkovic, R.; Zivkovic, M.; Grujovic N. Method of finite elements I, Faculty of Mechanical Engineering, Kragujevac, Serbia, 2010.

[9] Djordjevic, Z. Dynamic conduct composite shafts, PhD Thesis, Faculty of Engineering Kragujevac, Serbia, 2008.

[10] Djordjevic, Z.; Govedarovic, J. Influence angle of fiber orientation on dynamic characteristics of composite shaft. // Proceedings of the conference IRMES'04, Research and Development of Machine Elements and Systems, Kragujevac, Serbia, September 16÷17, 2004, pp. 637-642.

[11] Sevkat, E.; Tumer, H. Residual torsional properties of composite shafts subjected to impact. // Materials and Design, 51(2013), pp. 956-967.

[12] Mutasher, S. A. Prediction of the torsional strength of the hybrid aluminum/composite drive shaft// Materials and Design, 30(2009), pp. 215-220.

[13] Rompicharla, K.; Rambabu K. Design and analysis of drive shaft with composite materials. // Research Expo International Multidisciplinary Research Journal. 2, 2(2012), pp. 178-187.

[14] Djordjevic, Z.; Blagojevic, M.; Jovanovic S.; Vulovic S. Analysis of the Influence of the Fibre Type on Static and Dynamic Characteristics of Composite Shafts. // Scientific Technical Review, 61, 2(2011), pp. 35-40.

[15] Vijayarangan, S.; Rangaswamy, T.; Chandrashekar, R. A.; Venkatesh, T. V.; Anantharaman, K. Optimal design and analysis of automotive composite drive shaft. // International symposium of research students on materials science and engineering, India, 2004.

[16] Kim, H. S.; Kim, B. C.; Lim, T. S.; Lee, D. G. Foreign objects impact damage characteristics of aluminum/composite hybrid drive shaft. // Composite Structures, 66, 4(2004), pp. 377-389.

[17] Bert, C.W.; Kim, C. D. Analysis of buckling of hollow laminated composite drive shafts. // Composites Science and Technology, 53, (1995), pp. 343-351.

[18] Gubran, H. B. H. Dynamic of hybrid shafts. // Mechanics Research Communications, 32, (2005), pp. 368-374.

[19] Gubran, H. B. H.; Gupta, K. The effect of stacking sequence and coupling mechanisms on the natural frequencies of composite shafts. // Journal of sound and

vibration, 282, (2005), pp. 231-248.
[20] Simic, D. The theory and application of strain gauges, Faculty of Engineering Kragujevac, Serbia, 1972.
[21] Maksimovic, S. Postbuckling and initial failure analysis of layered composite structures using improved shell finite element. // J. Theoretical and Applied Mechanics, Special Volume 1, (2004).
[22] Djordjević, Z.; Atanasovska, I.; Blagojević, M.; Momčilović, D.; Miletić, M. The numerical analysis of strain and stress state of composite shaft. // 4th International Congress of Serbian Society of Mechanics, Vrnjačka Banja, June 3÷7, 2013, pp. 329-334.

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Location

Located in the Klang Valley, Kuala Lumpur is the capital and most populated city of Malaysia, and is ranked as the sixth most visited city in the world. The main in landmark in the city is the Petronas Twin Towers. Standing at 450m (1,483ft) they are the tallest twin buildings in the world, and together with the Kuala Lumpur Tower, dominate the skyline of the city.

Kuala Lumpur is the retail and fashion hub of Malaysia, being voted the fourth best city in the world for shopping. The city has over 66 shopping malls, and has designated numerous zones in the city to market locally manufactured products such as textiles and fabrics, including Chinatown which is home to Kuala Lumpur's Central Market.

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