THE 7TH INTERNATIONAL CONFERENCE RESEARCH AND DEVELOPMENT OF MECHANICAL ELEMENTS AND SYSTEMS

INFLUENCE KIND OF THE MATERIAL AND ANGLE OF FIBRES ORIENTATION ON STRESS AND STRAIN ANALYSIS OF COMPOSITE SHAFT

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Abstract: *Characteristics of composites (stiffness, resistance, thermal expansion and other) can vary depending on the type of the material used, quantity, angle of fibre orientation, etc. The selection of material depends on the life required, number of items, product shape complexity, accuracy of computation of optimal characteristics of composites and other. In some cases, the best results may be achieved by using a combination of composite and traditional metal materials. In this paper is developed the method of calculation composite shafts and the numerical model for that shaft is applied using numerical programs FEMAP i NXNASTRAN.*
Based on the recent researches, the conclusion is that the stress and strained state of the shaft has been reached and that all the information given in this papers recommends a numerous appliance of composite materials as it is already an increasing trend in the world.

Key words: *composite materials, composite shaft, stress, strain*

1. INTRODUCTION

Composite materials are obtained by combining two or more materials in order to get a new material with controlled properties, along with more favorable characteristics. These materials have significantly better properties than their component parts. They are mainly *mechanical*, such as strength, stiffness, toughness, etc.., *resistance to external influences*, such as temperature, humidity, chemical agents, abrasive action, etc.., *Longer service life* and the like.
Replacement of steel shaft by composite shaft is a novelty in the world, especially in our country. Composite materials were in the beginning of its implementation, as mentioned earlier, applied in aviation, while nowdays more is done on the analysis of their automotive industry usage.
The above paper overview relates to some, the most characteristic, work in this field.
Naveen Rastogi in his paper [5] presented the method for calculating the drive shaft which is applied to cars. He gave two important aspects calculation drive shaft: calculation of the composite shaft and calculation of joints between fittings and shafts, as well as discussion of the solution. Chih-Yung Chang, together with a group of authors in paper [6] described the vibration behavior of rotating composite shafts containing randomly oriented fibers. Mori-Tanaka's theory of "middle area" is adopted here to analyze the effect of arming fiber within composite material.. Effective elastic modules for composite materials have a function of the characteristics of individual parts, fiber volume and fiber orientation angle. D.G. Lee and other authors in [7] explained the new production methods of one-part, combined AL / composite drive shafts for cars with rear-wheel drive. Composite material consists of several layers which are made by the inner surface of the aluminum tubes. In paper [8], T. Rangaswamy and others gave a realistic calculation and an analysis of the composite drive shaft for power transmission, optimal calculation of one-part car drive shaft with rear-wheel drive using E-glass/epoksy and a highly modular and (NM) carbon / epoxy composite.

2. PORPERTIES OF COMPOSITE MATERIAL

Composite materials present strong, inseparable link of two or more component parts, united in the macroscopic size, non-destructive, all in order to obtain better mechanical and other characteristics, than possessed by constituent elements. Composite materials are macromechanic mixture of two or more materials with different physico-chemical and mechanical properties, mutually insoluble. The greatest advantage of composite materials is reflected in the fact that most of them use the best features of building materials and features that often receive such materials by themselves do not possess individually.

Composite materials consist of:

• discontinuous phase, ie. reinforcement (particles, beads, fibers), and

• continuous phase, ie. matrix.

Composite materials belong to the group of anisotropic materials and their mechanical properties depend very much on the angle of measurement of individual characteristics. Depending on the shape and composition of the composite, constituents are divided into: fiber, shell, skeleton, and laminated composites with particles (Figure1).

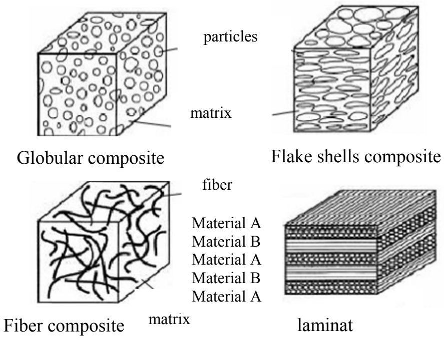

Fig.1. Particle reinforced composites

In the technical practice, metal and nonmetallic composites are used, which can be strengthened by particles, layers, or fibers. Today the most frequently used are fiber-reinforced polymer composites. Composite materials have a relatively high load stability even after partial damage, as a result of transferring the load across a large number of fibers. Also, they possess high resistance to concentrated stress, aggressive environment and corrosion, and they are characterized by a small speed of crack distribution, high internal damping, have a small thermal conductivity etc.

3. APPLICATION OF NUMERICAL METHODS TO STATIC ANALYSIS OF COMPOSITE SHAFTS

For the analysis of hollow shafts, as in the case with composite shafts, elements in the form of a shell, that is, in form of multilayered shells, are commonly used. For multilayered shell, characteristic is that, by appropriate orientation of fibers along with small thicknesses, high rigidity of the shell structure can be achieved. In formulating the final element of multilayer shells, calculation of all sizes is done in layers.

All numerical methods involve the use of computers and appropriate software. Nowadays in the world, as well as in our country, there are many software packages developed, such as NX Nastran, SAP, PAK, I-DEASm SESAM, COSSMOS/M, pal2, ANSYS... Basic characteristics of metallic materials (steel and aluminum) and composing materials that are commonly used for making shafts (carbon fiber / epoxy resin, glass fiber / epoxy resin, aramid fiber / epoxy resin, boron fiber / epoxy resin), which are being used in this paper as well, are given in Table 1.

Table 1. Basic features of materials

Material	E_1, MPa	E_2, MPa	G_{12}, MPa	ν	ρ, kg/m^3
Steel	210000	210000	83000	0,3	7830
Aluminium	70000	70000	28000	0,28	2600
Carbon fiber / epoxy resin	131600	8200	4500	0,281	1550
Glass fiber / epoxy resin	43300	14700	4400	0,3	2100
Aramid fiber / epoxy resin	81800	51000	1510	0,31	1380
Boron fiber / epoxy resin	211000	24100	6900	0,36	1967

Marks in table are: E_1-modulus in longitudinal direction; E_2 - modulus of elasticity in transverse direction; G_{12}-module-slip, ν - Poisson's ratio, ρ-density material. Dimensions of shafts, analyzed in this study are: the length is 1000 mm, mean radius of 50 mm, wall thickness of the ring cross section is 4 mm [1]. The shaft is supported at the ends, and in the middle of the range is exposed to static load of 1000N.

The model of the analyzed composite shafts obtained in FEMAP v9.3 software package is shown in Figure 2. For the analysis of isoparametric quadrangular final elements, multilayer shell forms are used, so that the shaft is divided into 8 elements in axial and 12 elements in the circular direction.

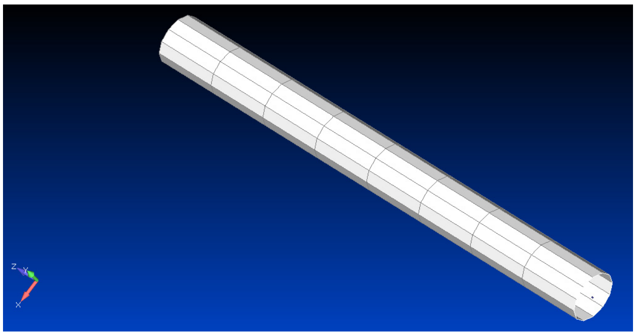

Fig. 2. Aluminum/composite shaft

Analysis procedure was initiated on the example of a metal shafts (steel and aluminum). Figures 3 and 4 are showed in deformed shape and displacement values for these materials shafts.

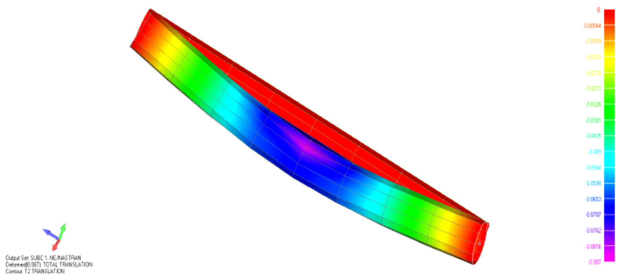

Figure 3. Values of steel shaft displacements

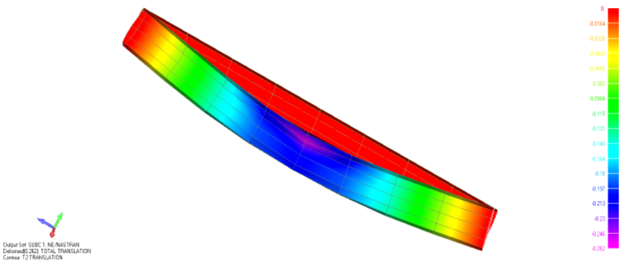

Fig. 4. Values of aluminium shaft displacement

Further proceedings of purely composite shafts are analyzed, which are made from materials whose characteristics are given in the table (carbon fiber / epoxy resin, glass fiber / epoxy resin, aramid fiber / epoxy resin and boron fiber / epoxy resin). The influence of material type on the values of shaft displacement and shafts deformations have been considered, as well as the effect of fiber orientation angles. Initially, the case when the fiber direction coincides with the long axis of shafts, has been considered (fibers are placed at an 0° angle).

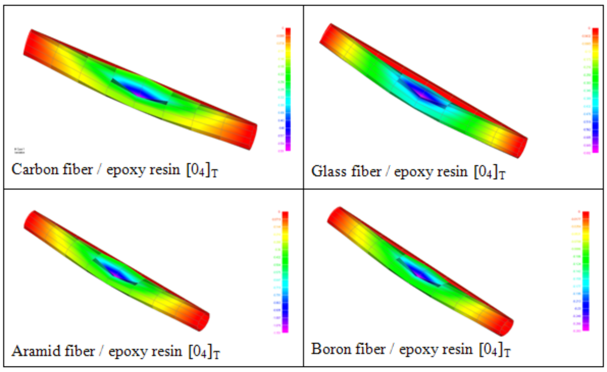

Fig. 5. Displacement values for the angle of fiber orientation $[0_4]_T$

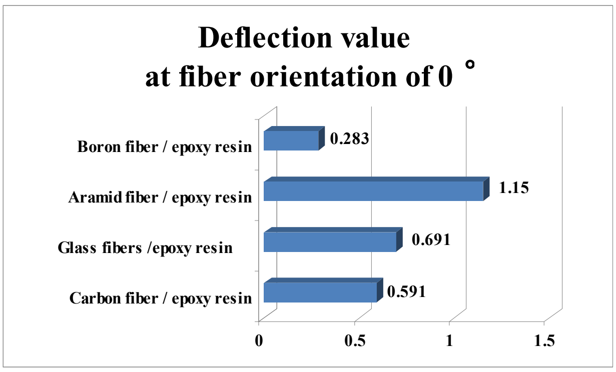

Fig. 6 Graphic representation of deflection value for different shaft materials

In Figure 5, and especially the graphic representation given in Figure 6 can be observed that the best features (the least value of deflection) have shafts made of boron fiber / epoxy resin and carbon fiber / epoxy resin, and the worst qualities have aramid fiber / epoxy resin shafts.

Behaviour of materials at the fiber orientation angle of 30°, can be seen in Figures 7 and 8.

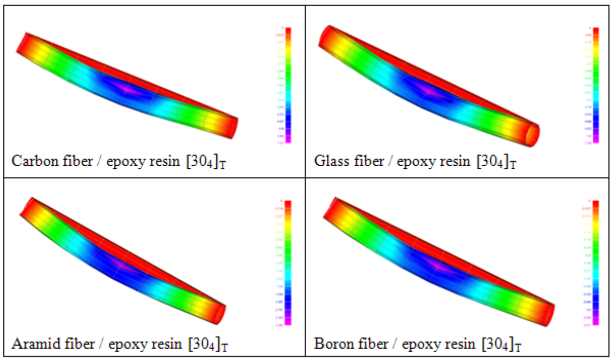

Fig. 7. Displacement values for fiber orientation angle $[30_4]_T$

In the case of fiber orientation of 30°, the same conclusions apply, as in the previous case. It has been noticed that aramid fibers show even worse traits, while the glass fibers and carbon fibers behave similarly.

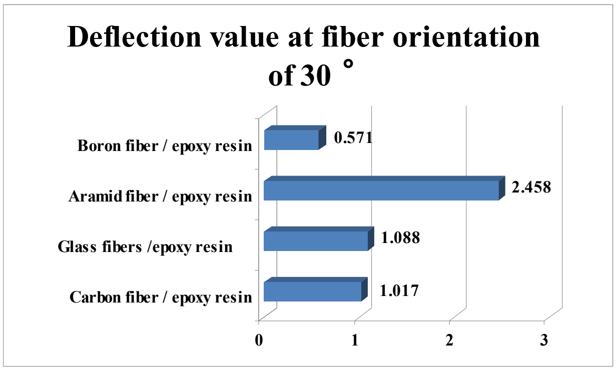

Fig. 8. Graphic representation of deflection value for different shafts materials

At fiber orientation of 90° (fibers are placed transversely to the longitudinal axis of shafts) the values calculated values of displacements are shown in Figures 9 and 10.

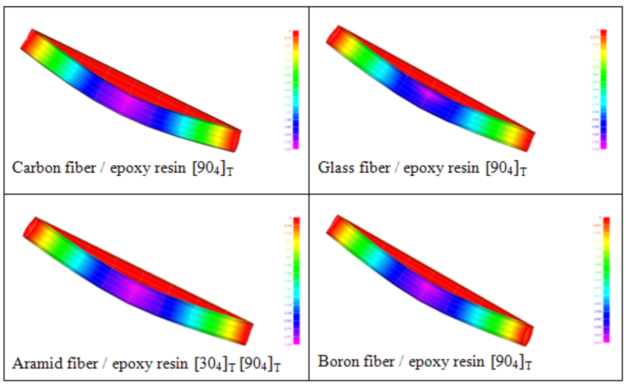

Fig. 9. Displacement values for fiber orientation angle $[90_4]_T$

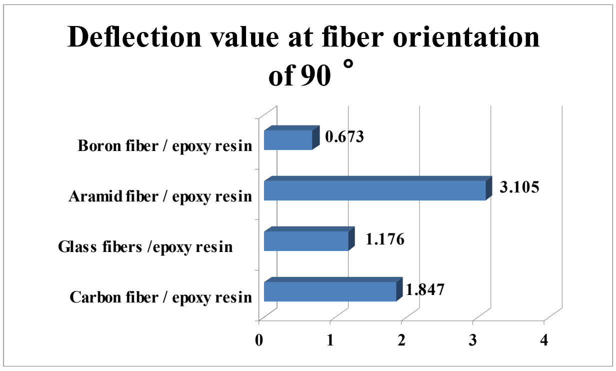

Fig. 10. Graphic representation of deflection value for different shafts materials

Unlike the previous two cases (0° and 30°), at angle of the fiber orientation of 90°, all materials show significantly poorer properties, especially the carbon fiber. It was to be expected as it relates to the elastic modulus in transverse direction, which is much smaller than the module in longitudinal direction. Hence, there is the following recommendations regarding orientation angles of these fibers which are not to be used in the preparation of bending shafts.

Finally it can be concluded, when material impact onvalue deflection is concerned, that the worst characteristics are of aramid fiber/epoxy resin , preferably boron and carbon fibers . Looking at figures 11. and 12., there is the obvious difference in value of the maximum deflection when it comes to aramid and carbon fiber / epoxy resin.

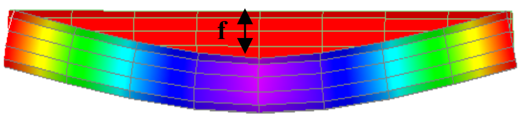

Fig. 11. The maximum shaft deflection of aramid fiber / epoxy resin

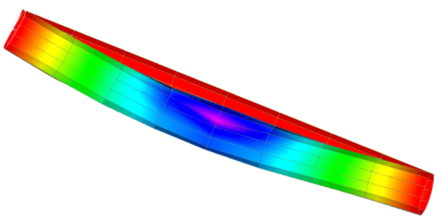

Fig. 12. The maximum shaft deflection of carbon fiber / epoxy resin

The way the angle of fiber orientation affects the value of the maximum deflection of bending shafts, may best be seen in Figure 13. for the case of carbon fiber / epoxy resin, that is, in Figure 14. for the case of glass fiber / epoxy resin.

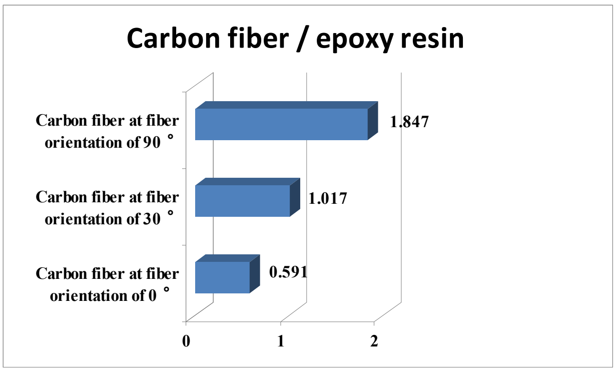

Fig. 13. The influence of fiber orientation angle on the deflection value (carbon fiber / epoxy resin)

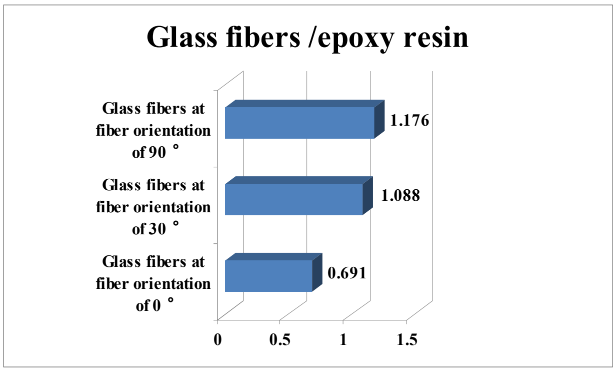

Fig. 14. The influence of fiber orientation angle on the deflection value (glass fiber / epoxy resin)

The influence of fiber orientation angle on the value of deflection for the case of aramid fiber / epoxy and boron fiber / epoxy resin can be seen in Figures 15 and 16

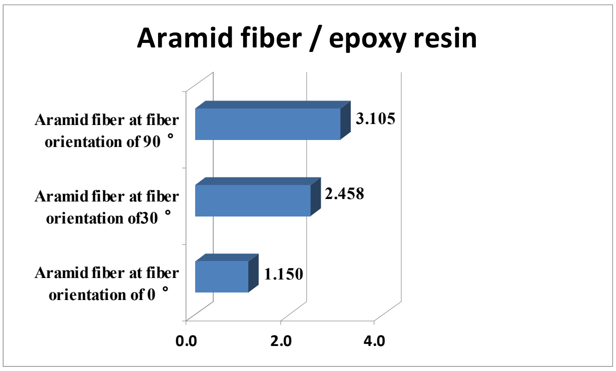

Fig. 15. The influence of fiber orientation angle on the deflection value (aramid fiber / epoxy resin)

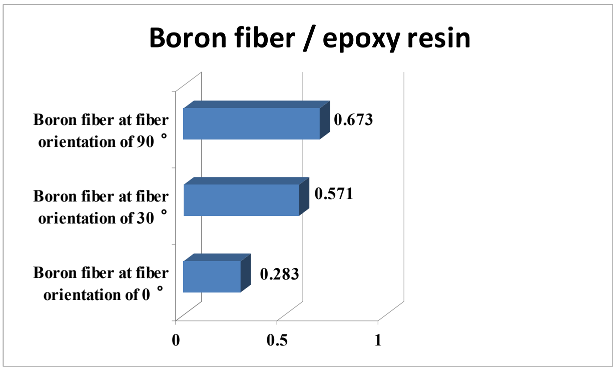

Fig. 16. The influence of fiber orientation angle on the deflection value (boron fiber / epoxy resin)

The lowest value of deflection at a load of bending, for all of the analyzed composite materials, is achieved at an angle of the 0° fiber orientation.
Besides the deformations, the stress values have been analyzed as well. The first analysis has been performed for case of the steel shafts on the existing model.
Analytically determined steel shafts stress value of is σ = 7.457 MPa. If this value is to be compared with the numerical value obtained from Figure 17, it can be noticed that there is a good compliance of results, since the difference does not exceed 1.8%, which is quite satisfactory.

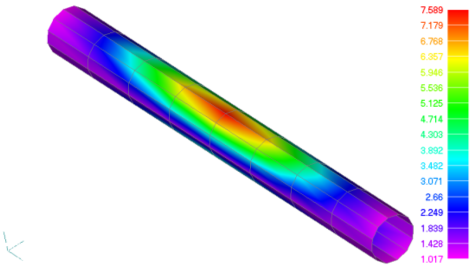

Fig. 17. Stress distribution for steel shaft case

When it comes to laminate composites, such as in this case, we should bear in mind that their strength depends on the strength of each layer which exists in it. Failure comes with the most critical stress state. In order to eliminate the appearance of failure in all laminate layers,it is necessary to define the area of allowed stress for each layer. Resistance of laminated shell depends on the ratio of the initial failure FI, the smaller the coefficient the greater the fracture resistance of a shell on the effect of loads.
According to Tsai-Wu's fracture criterion, condition to avoid failure in any of the layers is FI <1. This criterion is met for all types of analyzed material as well as all the angles of the fiber orientation.
In the further proceedings purely composite shafts have been analyzed. The influence of the type of material on the stress, as well as the effect of angles of fiber orientation, have been considered. Initially, the case when the direction of fibers is placed at an 0° angle is considered.

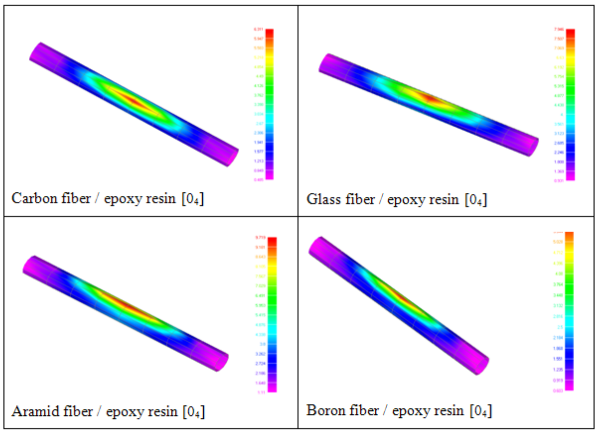

Fig. 18. Stress distribution for fiber orientation angle of 0°

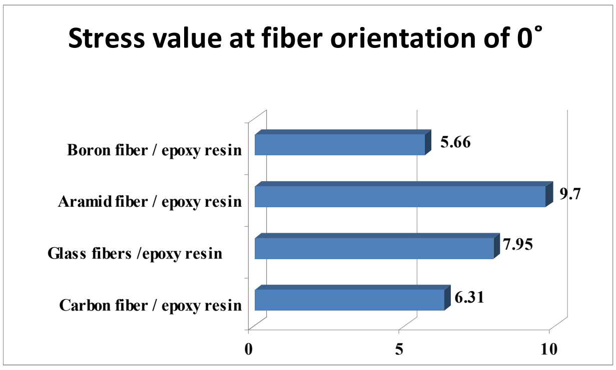

Fig. 19. Influence of composite materials on stress value

At fiber orientation of 90° degrees, obtained stress values are shown in Figure 20., and the effect of material type on the value of stress in Figure 21. Based on this analysis we can conclude that the best properties are of boron and carbon fibers.

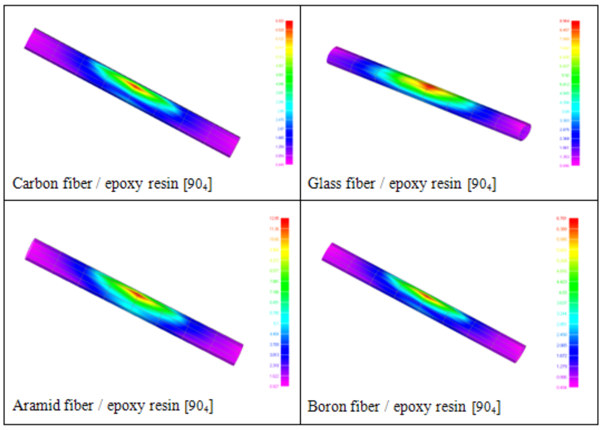

Fig. 20. Stress distribution for fiber orientation angle of 90°

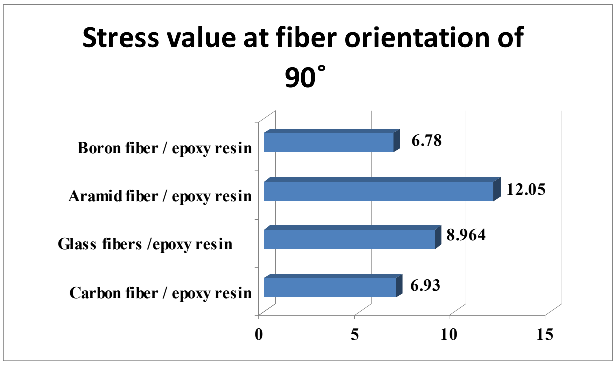

Fig. 21. Influence of composite materials on stress value

4. CONCLUSION

In this paper, the analysis of stress and deforming of composite materials shafts is done. In the paper, the model of a composite shafts is formed, and based upon composite materials features, numerical analysis has been carried out.

Creating of models and networks, as well as post-processing, is done in FEMAP 9.3, and for the analysis program NX NASTRAN has been used.

Firstly, the real dimension of shafts of steel and aluminum are analyzed, and obtained stress values and deflections are compared with analytically calculated values, upon which a good correlation of results is shown. Then, we moved to shaft analysis of composite carbon fiber / epoxy resin, glass fiber / epoxy resin, aramid fiber / epoxy and boron fiber / epoxy resin.

By changing the orientation angles of fibers in layers, their impact on the value of stress and deflection is considered, taking into account the initial failure ratio $FI < 1$ for each laminate layer, and value of this ratio to be approximately the same in each layer.

The best characteristics have boron and carbon fiber/epoxy resin, and it can be noticed in the results obtained in this paper, hence the resulting recommendations for their application in practice.

Based on the results and all the foregoing, it is recommended that extensive application of composite materials in all areas as well replacing conventional materials in preparation of by composite shafts.

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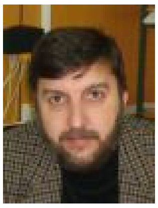

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