STRENGTH/STIFFNESS QUALITY CONTROL OF FABRIC REINFORCED COMPOSITE IN THICK-WALLED BEARING RINGS

R.S.Zinoviev[1], S. B. Sapozhnikov[2*], Yu.A.Merezhko[1]

[1] *Group of SPE "Polidor", Russia, 454048, Chelyabinsk, Fedorov str.1a*
[2] *South Ural State University, Physics Dept., Russia, 454080, Chelyabinsk, Lenin ave., 76*
**ssb@susu.ac.ru*

Keywords: thick-walled rings, stiffness, strength, NDT.

Abstract

The numerical and experimental methods for evaluation of transversal shear strength characteristics of wound glass-fabric reinforced plastics were developed for thick-walled bushings of journal bearings. An application of FEA for anisotropic structures with cylindrical symmetry such as bushings of bearings is suitable for finding the stress state and strength of material with use of information about load and mode of failure. The vibro-acoustics as NDT method for indirect checking of bearing bushing's strength and stiffness without the special sample preparation was developed. Eigenfrequencies are very sensitive to variation of volume fraction of glass fibers, quality of resin curing, presence of transverse cracks, etc.

1 Introduction

At the good practice of machine's design there is substitution of bronze bushing rings of journal bearings by split (or solid) composite ones, like PTFE, polyurethane, nylon, etc., filled by short fibers [1]. But these composites cannot be used for high loaded and slow rotated supports of road-making machines (blades of bulldozer, scraper, etc.) because of low strength and stiffness at radial compression/shear [2]. Only polymeric composites with *continuous* fibers are good in these cases simply using the dimensions of bronze bushes at the repair procedures of machines.

A structural composite for journal bearing bushing is a material system consisting two phases of microscopic scale (glass-fabric tape and cured resin), whose performance and properties are designed to be suitable for further application. The material and structure are made in several stages: winding of preimpregnated glass-fabric tape around a rotating mandrel under tension, curing wound mandrel in an oven under prescribed curing cycle and disassembling of mandrel for wound structure release [3]. Amount of resin, tension at winding and curing are only factors for influence on mechanical behaviors of composite material.

Bushing ring of journal bearing is very important part of machine and must be mechanically tested just after manufacturing and NDT before installation. So, radial compression, tension and shear strength of thick-walled wound rings are the subjects of this investigation. Because of curved shape of rings it is impossible to use standard test samples cut from the structure and that's the reason to develop indirect methods with wide use of FEA.

2 Material and technology

For making split bushings in this work we used satin-weaved glass-fiber tape and phenolic/epoxy resin with 10% vol. of ethanol for ease of soaking at impregnation process. Tension force of tape was about 5 kilo/cm to provide consolidation of prepreg on mandrel during circumferential winding. IR-preheating of mandrel was up to 70-80°C for decreasing of resin viscosity. After winding the mandrel wrapped over by cotton tape with tension force about 6 kilo/cm. Typical oven curing process is: 90°C/2hrs, 120°C/2hrs, 160°C /8hrs and cooling with oven (about 5-10°C/hr for relaxation of fiber/matrix cure stresses and prevent transverse cracks). After machining dimensions of split rings are: outer diameter D=120 mm, thickness h=6 mm, width b=30 mm. The density of cured material was 1.68-1.72 g/cm^3. The average volume fraction of glass fiber was 38%. For flat plate of GFRP with close density and fiber volume fraction orthotropic elasticity moduli were determined previously (Table 1). Here *x* and *y* – warp and weft directions, *z* – transverse direction.

E_z	E_x	E_y	v_{xz}	v_{xy}	v_{yz}	G_{xy}	G_{xz}	G_{yz}
MPa			-			MPa		
5800	14900	14900	0,05	0,15	0,05	3200	2900	2900

Table 1. Orthotropic elasticity moduli of GFRP composite.

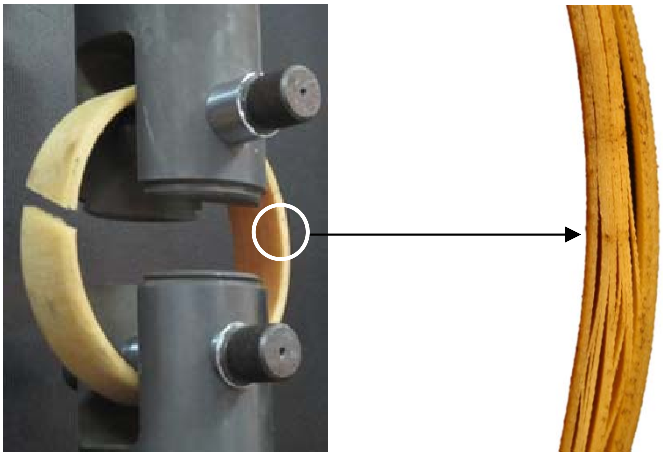
Maximum working pressure between journal and GFRP bushing is about 200 MPa and maximum shear stress about 40 MPa (coefficient of friction is 0.20). So, radial compressive strength should be at least 300 MPa and shear strength - 60 MPa to have safety factor 1.5.
It is clear that variation of tape tension force may change of prepreg consolidation conditions, amount of resin into layer and mechanical behaviors through variation of fiber volume fraction and density of material. Variation of curing parameters may change the quality of polymerization of resin and interlaminar strength. So, we need to have simple and reliable methods to check valuable mechanical behaviors or ring's material just testing split rings.

3 Testing methods

During all tests (real and numerical) we assumed that material of rings is locally orthotropic, homogeneous and stress-free at initial state. All real tests were provided at twin-screw universal testing machine INSTRON 5882. Applied load was measured by 5 kN load cell and sample deflection – by clamp displacement. Rate of displacement was 10 mm/min.

3.1.Tension

Tension of ring creates significant unbending moment in cross section against split which increases of radius of ring curvature and creates transversal tensile stress and delamination (Fig.1).
Typical diagrams "load – clamp displacement" is shown on Fig.2, where small jumps correspond sliding of ring on supports (round bars), large jumps – failure (delamination, transverse cracking). Failure loads are in quite large dispersion: 220-400 N. Average failure load is P=305 N. Results of numerical experiments with FEA (Ansys Workbench) with cylindrical coordinate system shown below (Fig.3, 4).
Maximum value of circumferential stress can be calculated [4] as $\sigma_Y \approx$ 6PR/(bh^2)+P/(bh) = = 6x300x57/(30x6^2) +300/(30x6)= 96.7 MPa, here R – middle radius of ring, b and h – width and thickness. Numerical experiment shows value of σ_Y = 113 MPa. Error is about 15%.



a b

Figure 1. Split ring tension test. Sample and fixture (a), delamination (b).

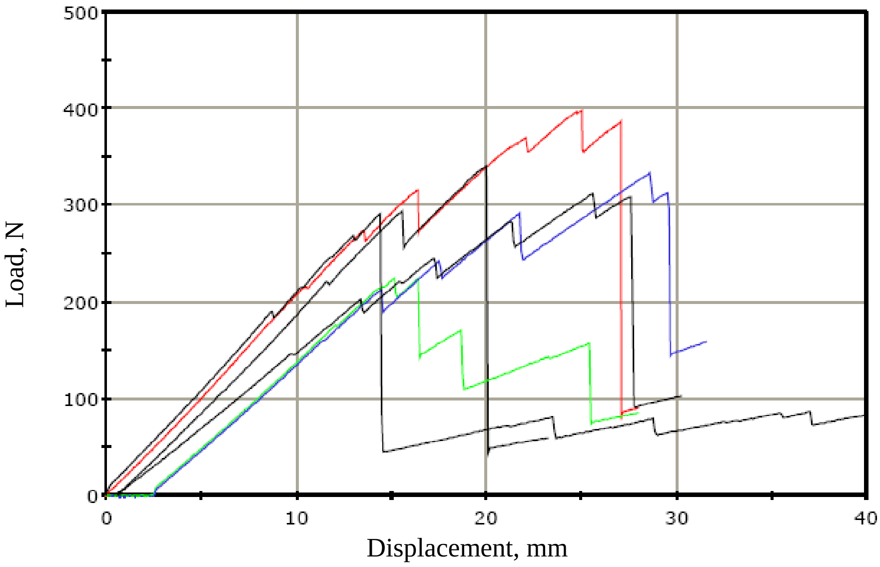
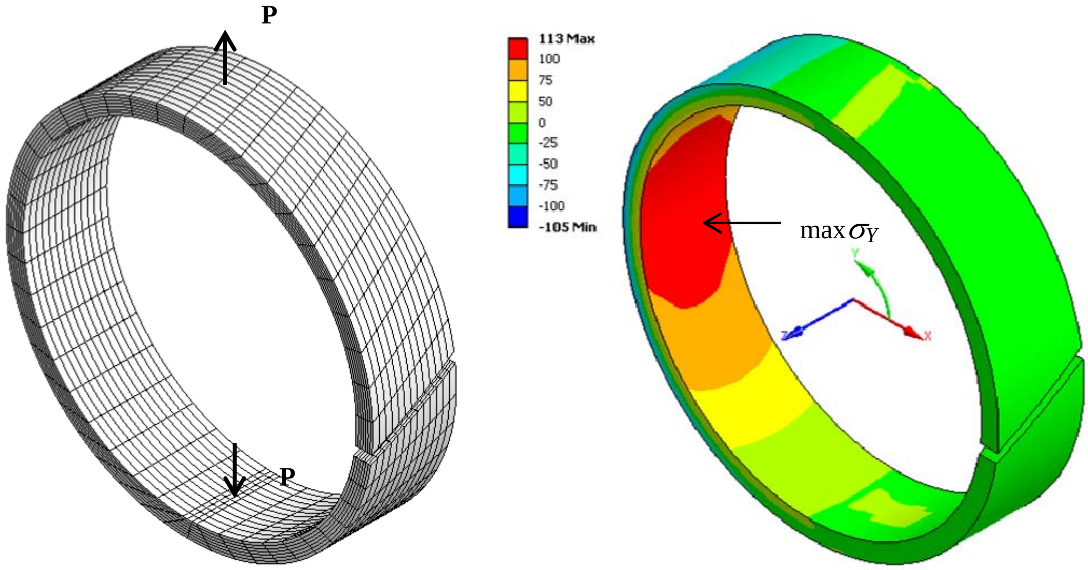


Figure 2. "Load – displacement" curves for tensile testing of split rings (outer diameter 120 mm, thickness 6 mm, width 30 mm)



a b

Figure.3. FE mesh (a) and circumferential stress σ_Y (b).

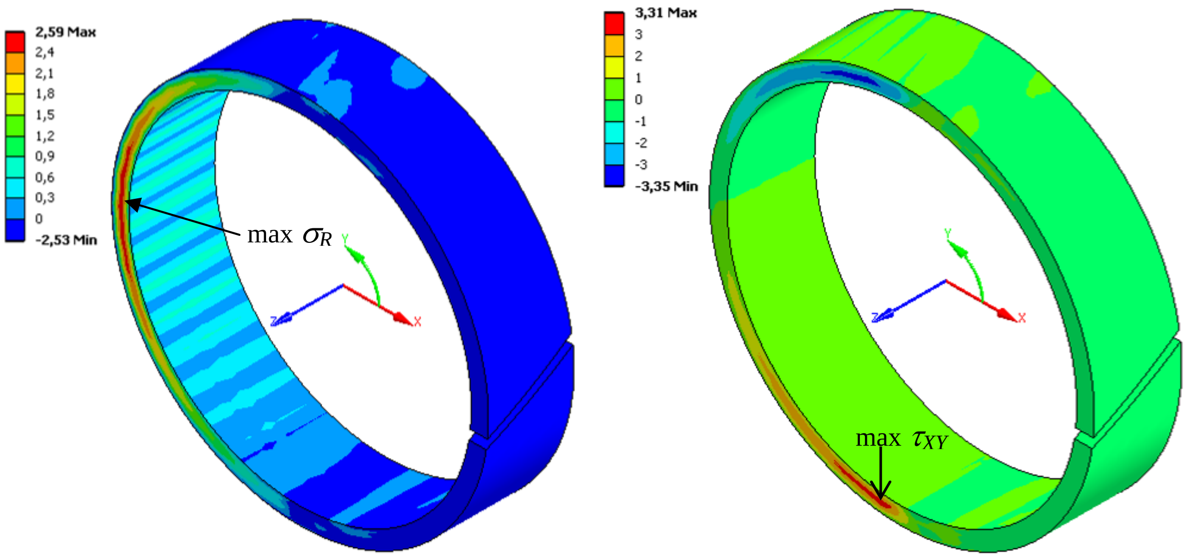


Figure.4. Transverse stress σ_X (a) and shear stress τ_{XY} (b).

According [5], for split ring transverse tensile stress can be estimated as $\sigma_R \approx 1.5P/(bh) =$ $=1.5x300/(30x6)=2.63$ MPa. Numerical experiment shows value of σ_R = 2.59 MPa. Error is less then 1%.

Maximum of shear stress close to maximum of transverse stress and can also be the reason of ring failure, because for GFRPs and CFRPs shear strength typically of 1.3-1.6 times more than transverse tensile strength [6]. It should be noticed that residual tensile transversal stresses may significantly influence on the transverse strength and ratio 1.3-1.6 can change.

3.2. Radial compression

For evaluation of radial compression strength there was made a special fixture consists of two parts and can uniform compress a piece of GFRP ring by using coinciding curved surfaces of lower, sample and upper parts (Fig.5).

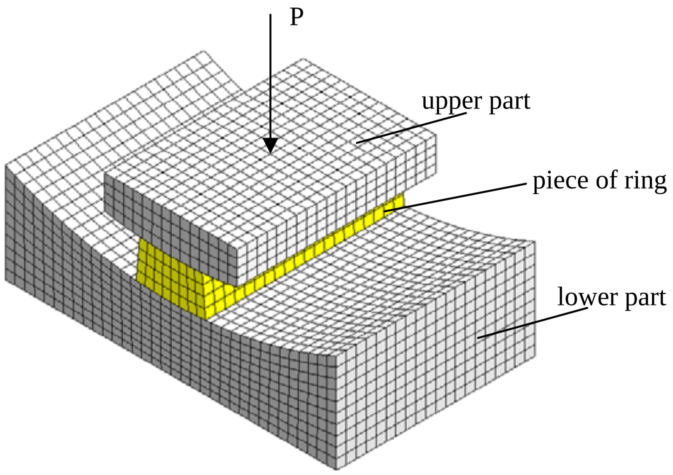


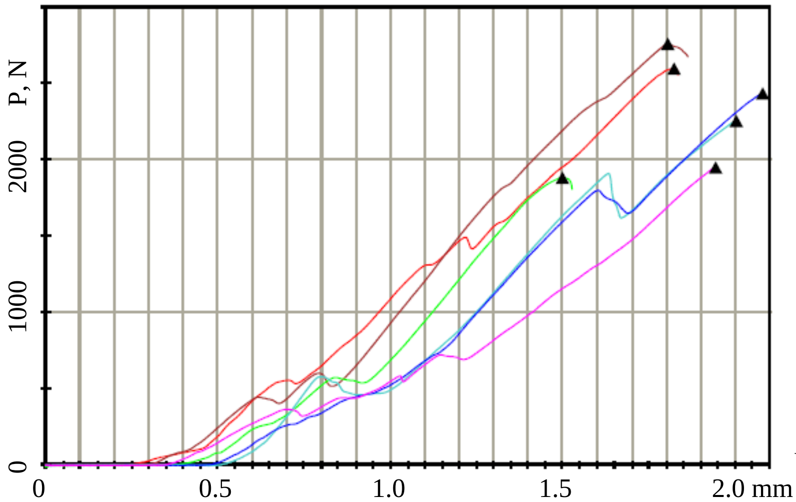
Figure.5. Fixture (FEA mesh) for compression of ring piece.

Radial compressive strength received with this fixture is 320-350 MPa, that is good enough for applications.

3.3. Short curved 'beam' shear

If we take the piece of ring with central angle about 45-60°, and load it with 3-point bending (Fig.6a, lubricated supports), we may obtain interlaminar shear failure. This positioning of test sample delivered negative transversal stresses (Fig.7c) and interlaminar shear became reality.

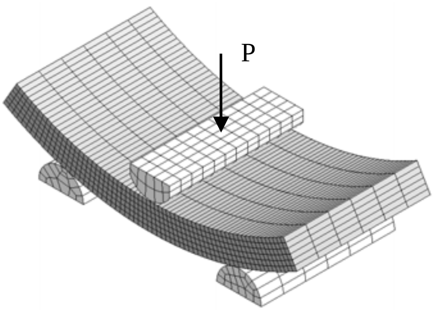
a



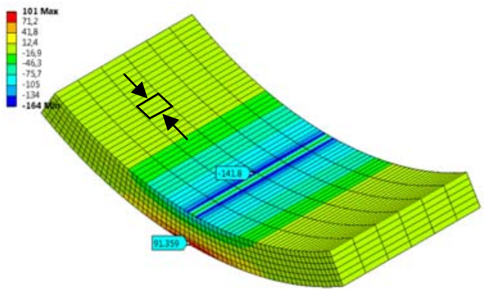
b

Figure.6. Loading scheme for short beam bending/shearing (ring piece) with roller support. Fixture (a) and diagrams 'load – deflection' of bending (b)

Failure loads are in the range 1.88-2.76 kN (Fig 6b). For average failure load P=2.2 kN stress state of curved beam is shown on Fig.7 (a-d).



a



b

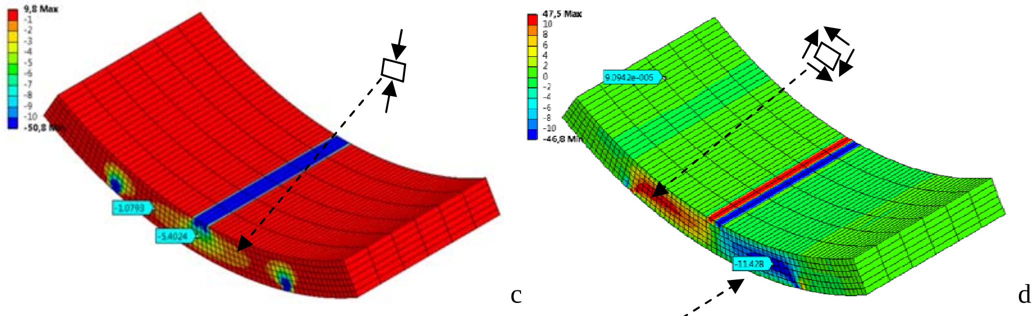
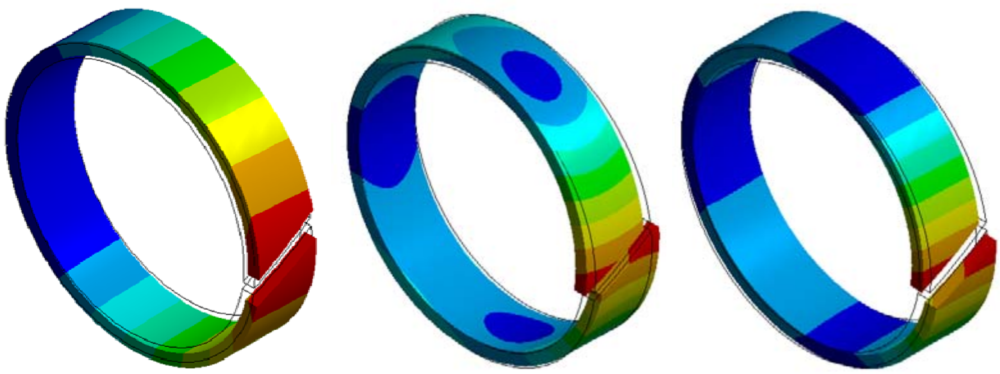


Figure.7. Stress state for short beam bending/shearing (ring piece) with roller support.
FE mesh (a), circumferential stress σ_Y (b), transverse stress σ_X (c) and shear stress τ_{XY} (d).

Here it can be seen shear strength τ_{XY} =11.4 MPa and compressive radial stress only 1.1 MPa. Circumferential stress is much less the strength and equal σ_Y = 142 MPa.
Compare given values of stress at the failure load with typical strength of GFRPs it can be noticed that GFRP of wound ring is *very weak* because of presence of paraffin emulsion wetting (in this case glass fiber tape was not cleaned before resin impregnation). After proper cleaning/bleaching transversal and shear strength increased significantly, so, circumferential stresses became critical – failure occurs on outer surface in compression zone.

3.4. Vibro-acoustics

Short impact excitation of ring vibrations can deliver the information about several eigenfrequencies for bending and torsion modes. We use laptop microphone and software (Nero WaveEditor and PowerGraph) to record acoustic signal and provide vibration spectrum analysis. Three first ring eigenfrequencies are: 90.2, 108 and 201 Hz. FEA modeling shows 89.9, 106.7 and 195.9 Hz (Fig.7).



89.8 Hz 106.7 Hz 195.9 Hz

Figure.7. Modes and frequencies of first free vibrations of ring (bending-1/torsion-1/bending-2).

For first three modes discrepancies of experimental and numerical eigenfrequencies are less than 2%. If curing was not so good all elastic behaviors will be less than right values. For example 10% decreasing of elastic moduli will get about 5% decreasing of eigenfrequencies. This variation can be easy determined experimentally.
If delamination occurs in cross section against slit (overloading at handling or so) first and second bending frequencies remain approximately the same, but torsion-1 frequency falls down 50-80%.

Conclusion

There were introduced two testing techniques: quasi-static (tension and bending) to investigate the strength characteristics and vibro-acoustic as NDT (bending/torsion during

short impact of free structure) for checking quality of curing matrix of bushing ring of journal bearing made of wound GFRP.
It was shown that technological errors like remaining of paraffin emulsion wetting on glass fabric before resin impregnation can ten times decrease of interlaminar transversal/shear strength. At the same case compressive strength is good enough and eigenfrequencies remain the same as for defectless (bleached fabric and fully cured resin) bushes.
So, it needs to combine fracture tests and NDT for complex evaluation of quality these very important parts of machines.

References

[1] Neale M. J. *The Tribology handbook (2nd ed.).* Butterworth-Heinemann, Oxford, 1995.
[2] Zinoviev R.S., Merezhko Yu.A, Yarosh V.G. *An experience of development of antifriction sliding bearings made of reinforced thermosets* in "Problems of nonhomogeneous structures design", Proc. of 3rd Russian school. Miass, Miass scientific and educational center, pp. 57–77 (1995).
[3] Daniel I.M., Ishai O. *Engineering Mechanics of Composite Materials*. Oxford university press, New York, Oxford, 2006.
[4] Beer F.P., Johnson E.R. *Mechanics of Materials*, 2nd ed., McGraw-Hill, New York, 1992.
[5] Hiel C.C., Sumich M., Chappell D.P. A Curved Beam Test for Determination of Interlaminar Tensile Strength of a Laminated Composite. *J. Composite Materials,* **25**, pp.854-868 (1991).
[6] Sapozhnikov S.B. *Defects and Strength of Reinforced Plastics, ChSTU, Chelyabinsk, 1994.*