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Evaluation of static and fatigue strength of long fiber GRP composite material considering moisture effects

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ABSTRACT

The paper presents results of a partial experimental programme of evaluation of static mechanical and fatigue properties of long glass-fiber reinforced polymer composite material with a multiaxial orientation of glass fibers to be used for a manufacture of the flywheel hub disc, the main component of the storage unit accumulating kinetic energy of a vehicle during braking for further use during acceleration. Though humidity is not supposed to be an issue in operation of the unit, an experimental programme evaluating the material static strength and durability under combination of static load with vibration component was carried out to complete the overall general material characterisation. Study of an effect of absorbed moisture was a part of the experimental work. Water absorption was a long-term process, without saturation even after several months. Degradation of strength and fatigue properties due to the absorbed distilled water was confirmed for this material. The material sensitivity on vibration component of the load, even with quite low amplitude of 10% of the static load was ascertained. Damage accumulation and continuous stiffness reduction during fatigue tests, which rate was connected with final durability, was an important phenomenon.

1. Introduction

The path towards sustainable transport requires the development of integrated transport strategies, which have to consider innovative forms of public transport and innovative vehicle types. An example is a zero emissions vehicle (bus) based on a hybrid electric drive line. Novel features of such concept include the use of a small on-board energy store – flywheel to store the energy that would otherwise be lost on braking [1]. The concept of the zero emission vehicles is based on an integration of existing technologies including high efficiency electric motor/generators, compact power convertor drives and a lightweight flywheel storage system based on the use of glass fiber reinforced plastics.

One of the essential components of the propulsion system is the flywheel unit, which enables all the kinetic energy of a fully loaded bus to be stored during braking from the maximum speed to arrest [2]. The energy is transferred by repeated cycling of the flywheel rotor between low and high speed. The flywheel is of a hub/rim type, with the energy stored in a thick rim whilst the flexible hub disc is able to follow the rim as it expands under centrifugal loading. There are very high claims on the safety and reliability of the energy storage unit during its operation with rotor integrity being preserved through a very narrow gap (2 mm) between the rotor and the its safety casing.

Exacting demands and high safety factors are applied in road and railway transports, particularly if innovative advanced materials like fiber reinforced polymer composites are to be used [3]. One of the problems of wide application of polymer composites in transport vehicles is that even quite well-know techniques as global–local approaches, which can be used for designing with good results, are not yet usually implemented in commercial codes [4]. This is the reason why strict criteria are applied during the certification process of innovative transport vehicles containing heavy loaded GRP materials. Safety and reliability has to be justified by both detailed calculations and experimental results of material characterisation and full size component tests.

An important, fundamental part of the safety evaluation was an experimental material characterisation programme of an evaluation of static mechanical and fatigue properties the material with biaxial orientation of glass fabric and multiaxial orientation used in the flywheel disc hub, the main component of the storage unit. An experimental programme evaluating the material static strength at different loading and durability under combination of static load with dynamic component was carried out to complete the overall general material characterisation. Though humidity is a generic issue in the operation of flywheel rotor as it operates in vacuum, study of an effect of absorbed moisture on the static

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mechanical and fatigue properties formed part of the experimental work.

The paper deals with some specific steps of the experimental characterisation, namely (i) evaluation of static strength at tension and three-point-bending (3 PB) of basic material with biaxial fiber orientation, (ii) static strength and fatigue tests at 3 PB loading of specimens taken from full-size flywheel hub disc with multiaxial orientation of fibers, (iii) evaluation of distilled water absorption and (iv) fatigue tests at 3 PB of specimens of the disc at loading with cyclic amplitude corresponding to 10% of static load. The works were performed within the project EUREKA E! 2462 TRUS – Zero Emission Public Transport, in a collaboration with a wide European consortium of partners.

2. Experimental material

The material supplied by OCV was a biaxial balanced glass fabric designated EBX hd 780 where hd refers to high drape and 780 refers to the mass in g/m^2. An isotropic polyester resin Crystic 199 (blend 9229PA) was supplied by Scott Bader and catalyst Trigonox 44B (Azko Nobel). Two plates of thickness 7 mm with manufacturing codes TFD7 and TFD8 were prepared for the basic material characterisation programme. These plates were made from nine layers of fabric by hand lay up at ambient temperature with a fiber fraction of 46%. The material was post-cured at 80 °C for 3 h. The stacking sequence, which is known to be very important and can significantly affect elastic modulus and stiffness reduction [5,6] is shown in Fig. 1 and shows that the fabric lay up is not symmetric. Zero degrees orientation was designed to be parallel to the width of the plate (250 mm) and 90° orientation was considered to be that in the length direction (260 mm). Two types of specimens were manufactured in both the different directions: (i) specimens for static tension tests of dimensions 25 × 250 mm, gauge length 170 mm, (ii) specimens for static three-point bend (3 PB) tests of dimensions 25 × 180 mm, test span 160 mm.

The flywheel hub disc of diameter 362 mm was manufactured from the same glass fabric with each fabric layer being offset by 40° to maximise the homogeneity of mechanical properties independent of the orientation. The disc was sectioned in order to manufacture 3 PB specimens with different orientations as shown in Fig. 2. It should be emphasized that these specimens were not of a standard type due to their curvature. Moreover, the maximum possible span-to-thickness ratio only was 14:1 and not 20:1, as recommended in standards to minimise shear stresses.

Static tension and 3 PB tests were performed on electromechanical machine INSTRON 1185 equipped with computer controlled videoextensometer NG of Messphysik Materials Testing GmbH to record strain and deflection, respectively. Global specimen deformation during static tests was measured on the base length of 100 mm. As regards the water absorption measurement, specimens were immersed in distilled water and weight increments gradually evaluated. The total period of immersion was 120 days, i.e. 2880 h. According to the literature, such a long period usually results in a noticeable reduction of strength [7]. The distilled water was used considering the fact that this type of water or even deionised one has a strong ability to deteriorate resin and the interface between fibers and resin [8].

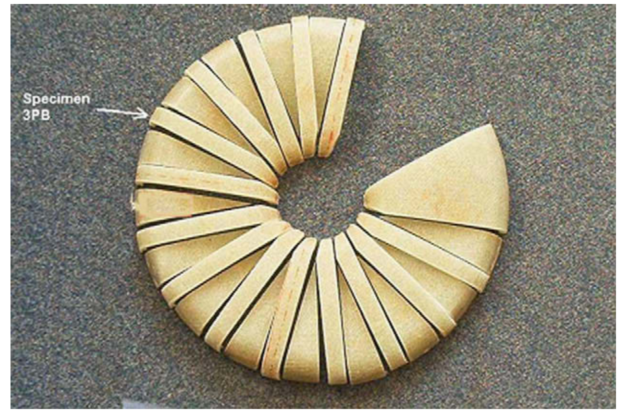

Fig. 2. Sectioning of hub disc prototype to obtain specimens for bending tests.

3. Experimental results and discussion

3.1. Static tensile and bending properties

Static stress–strain/deflection curves of specimens of the two plates are in Fig. 3. An interesting phenomenon was a bilinear behaviour of the material during tension test. There was a distinctly higher *E*-modulus in the first loading stage to 70–75 MPa in comparison with the second stage. The bilinearity can be explained by a different strength of the material in the direction of fibers and perpendicular to them. The stress value corresponding to the *E*-modulus change likely corresponds to the material strength of fibers in the transverse direction and so, in the second stage, just the longitudinal fibers have carrying capacity. Such bilinearity was not observed in the case of bending, when damage occurred on the tensile side of the specimens and continuously developed from the tensile surface through the thickness.

Results of all static tests are summarised in Table 1. There was a 15–21% difference in properties between the two plates. No influ-

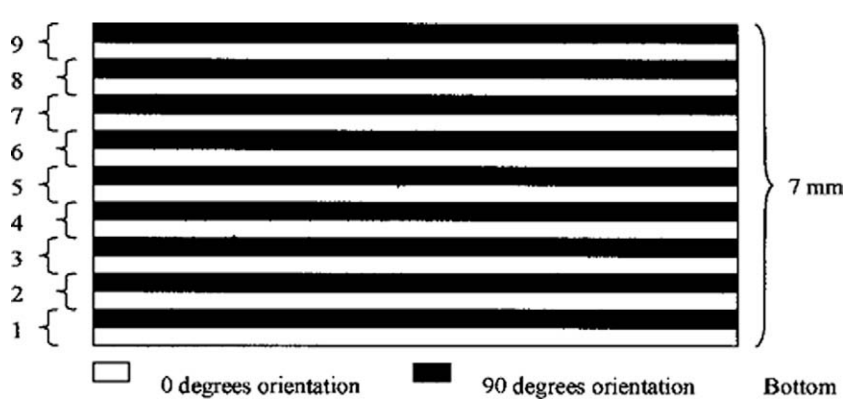

Fig. 1. Stacking sequence of basic material plates with biaxial orientation of glass fibers.