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Monitoring of Internal Damage of Glass Fibre Reinforced Composite Components Using Strain Measurements with Strain Gauges and Fibre Optic Sensors

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Abstract. Glass fibre reinforced polymer (GRP) composites are perspective materials for manufacture of components in different machinery applications. Favourable characteristics of these materials include very high specific strength, ratio of static and dynamic stiffness, particularly beneficial in dynamically loaded structures, and potentially excellent fatigue strength provided that there are no latent internal imperfections, occurring usually in the manufacture process. Defects like insufficient wet-out of glass fibres by resin result in significant reduction of static and fatigue strength in shear. If the component thickness is high and it is loaded by bending, considerable shear stresses occur in the neutral plane, which can cause premature shear failure of the component. Results of static and fatigue tests in bending of full-scale models of longitudinal frames of railway freight vehicle bogies, manufactured from GRP polyester composites, are shown and analysed in the paper. Surface strains measured using strain gauges were monitored during the component loading, its continuous damage and were analysed. The results are in a good agreement with the subsurface strains evaluated using fibre optic sensors embedded in the component during the manufacture process. Asymmetry of strains, both internal and surface, was connected with internal defects and consequently reduced strength. On the contrary, very good fatigue resistance was characteristic for components, where strain values were symmetrical.

Introduction

Glass fibre reinforced plastics (GRP) have been used as a structural material already for more than fifty years [1]. The advanced GRP designs utilise the intrinsic properties of fibre reinforced plastics such as high working strains and internal damping, low density and good fatigue performance [2]. On the other hand, wide application of polymer composites in heavy loaded structures, like e.g. transport vehicles, is still rather limited. One of the reasons is that 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 [3].

EUREKA Eurobogie project (E!1841), coordinated by R.M. Mayer, Sciotech Projects Ltd., has been aimed at an advanced design, manufacture and verification of a railway GRP bogie. The bogie has been designed for high speed freight vehicles whose upper and lower frames act as the suspension (Fig. 1). Innovative aspects of the designs include lateral compliance to facilitate wheel sets going around curves without steering, reductions in noise and vibration, lower track forces and functional integration of components.

For fibre composites to be used with confidence in primary load bearing structures, methods of monitoring strains in service use are essential. The damage accumulation measurement can be performed using a number of different non-destructive techniques like replication, light and electron microscopy, X-ray radiography, ultrasonics, stiffness change and thermography [4]. Most of these methods are, however suitable for laboratory purposes rather than in-service evaluation. For glass reinforced plastic (GRP) beams with thicknesses greater than say 40 mm, no suitable non destructive test technique is available which limits the range of applications for these materials. So the partners in the Eurobogie project have investigated the potential of fibre optic strain sensors (FOS) with high tensile strength, i.e. Draw Tower fibre Bragg Gratings (DTG®s), to monitor strains for components moulded by different methods. The programme contained extensive surface strain analyses during the component loading using strain gauges. The results, correlated with the FOS measurement, performed by E. Voet from FBGS International Belgium, are described in this paper.

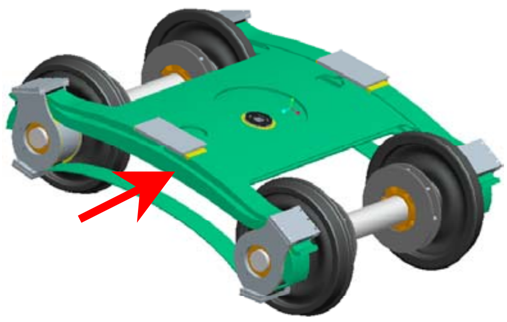

Fig. 1 Scheme of GRP railway bogie, the massive side frame indicated by the

Experiments

Manufacture of the components. The side arms of the lower GRP bogie frame are 3.0 m long, 192 mm wide with a thickness tapering from 115 mm in the centre to 75 mm adjacent to the wheel sets. Some 104 layers of uni-directional glass fabric were successively laid up inside a dedicated 4 part mould.

As with the hand lay up beams, 4 optical fibres were tensioned on the 10th fabric layer from the tensile surface and then the remaining 94 glass layers added. The out coming FOS cables were then wrapped in a protective polystyrene box, the mould closed and catalysed resin injected and cured. The 84 kg beam was then demoulded and post cured up to 120 ^{o}C. After post curing, the fibre optic sensors were checked to ensure that the moulding and subsequent curing had not induced change in the condition of the sensors. No changes were detected.

Preparation of tests. Fifteen strain gauges (SGs) were bonded to the upper (compression) and bottom (tension) surfaces of the main beam, in the longitudinal direction. Different positions of the SGs enabled to evaluate longitudinal strains at different beam areas. Some SGs were attached close to the inside positions of the FOSs. The positions of both SGs and FOSs are schematically documented in Fig. 2 – FOSs in the upper part and SGs in the lower part of Fig. 2. Positions of FOSs 4a and 2b correspond almost exactly to SG4, position of FOS 4b approximately to SG2 and positions of FOSs 3a and 1b correspond to SG 7.

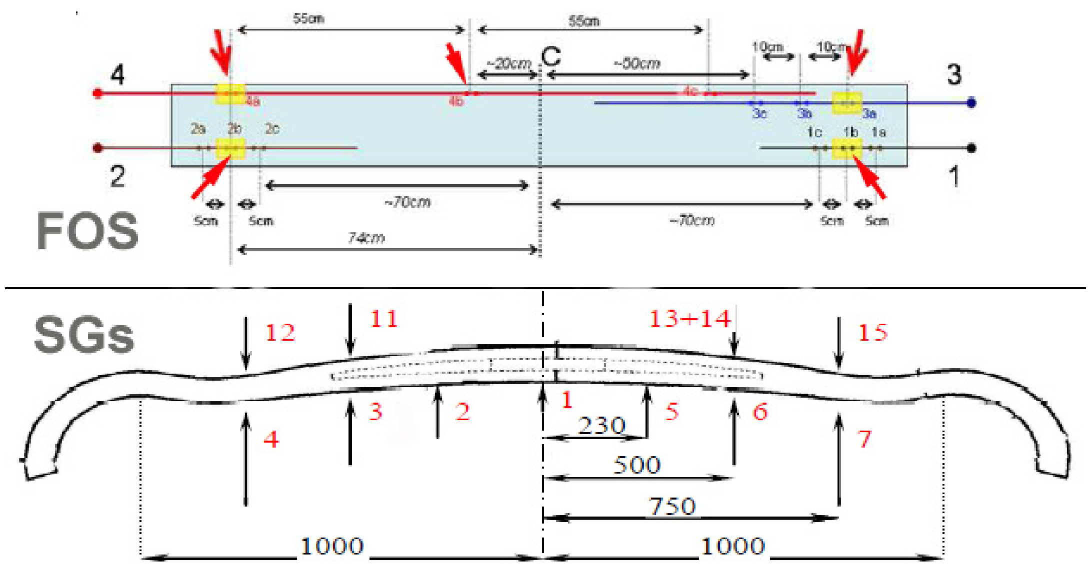

Fig. 2 Scheme of positions of FOSs (inside the component) and SGs (on the surface)

Results and Discussion

The main longitudinal beam was assembled with axle boxes and so called axle tie in the bottom. The component was supported on rollers and vertically loaded at its centre. There were considerable differences between values of symmetrically placed on the right and left sides, respectively. At the load of 62 kN, first failure occurred. Examples of results are shown in Figs. 3 and 4.

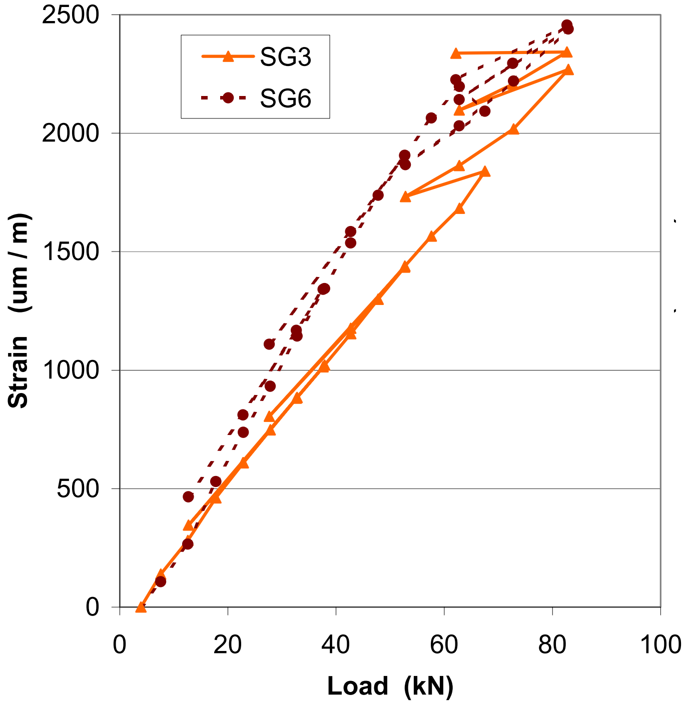

Fig. 3 Load-strain curves measured with SGs 3 and 6, bonded symmetrically on tensile surface

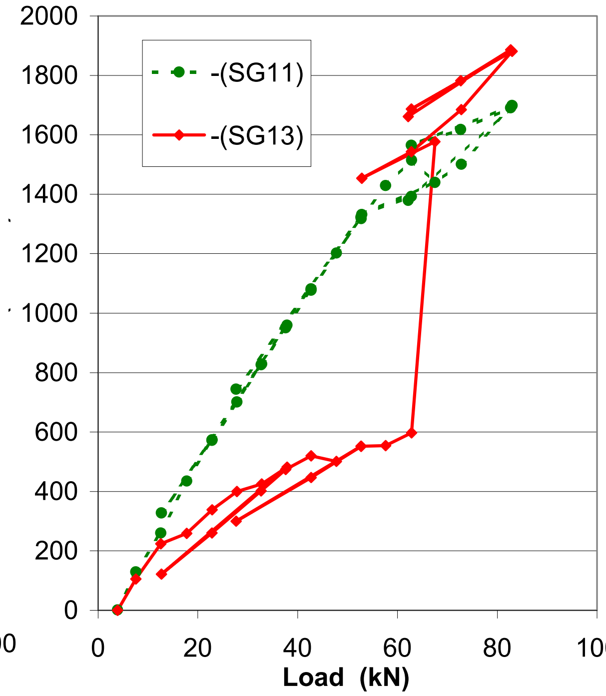

Fig. 4 Load-strain curves measured with SGs 11 and 13, bonded on compression surface

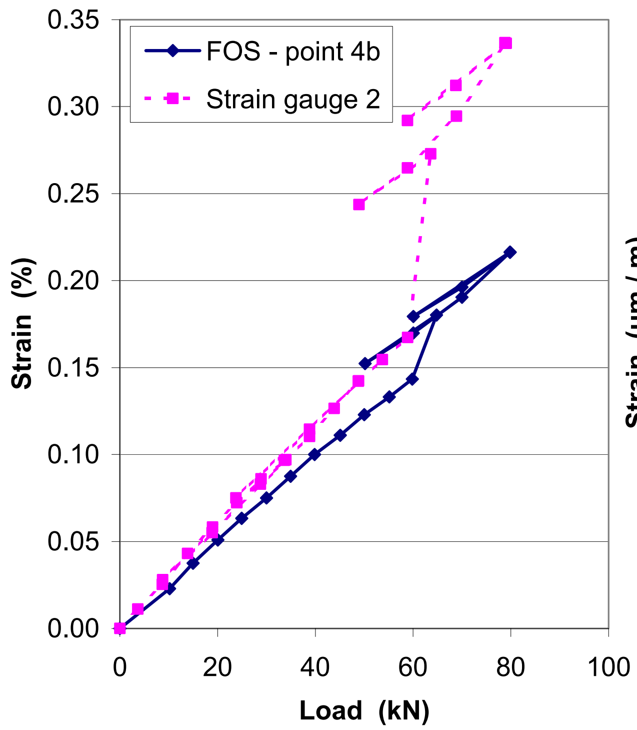

Fig. 5 Comparison of load-strain curves measured with SGs 2 and FOS 4b, respectively

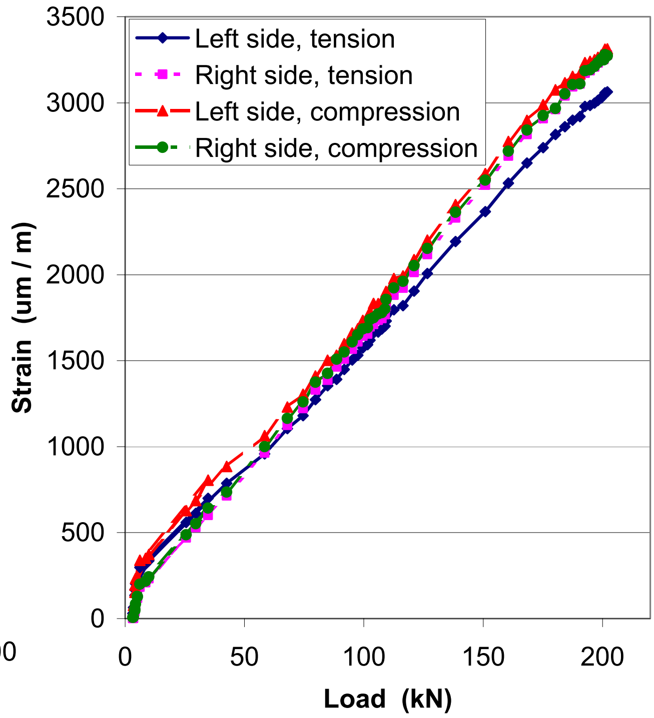

Fig. 6 Almost identical load-strain curves at equal positions in case of high quality beam

There are several points to be discussed. Starting with diagrams in Figs. 3 and 4, there are significant differences between surface strains on the right and left sides, as well as differences between absolute values of tension (bottom) and compression (top) sides of the beam. Nevertheless, these values should be theoretically identical, as in Fig. 8, where just tensile strain on the left side is slightly lower at high load. These result indicate considerable internal imperfections in the beam documented in Figs. 3-5, where internal delamination resulted in strain redistribution from the beginning of loading and then much more progressive redistribution after the first shear partial failure at the 62 kN static load.

Concerning the comparison of SG and FOS measurement (Fig. 5), the results are very consistent. Before the shear failure, at loads up to 60 kN, FOS values measured 10 mm bellow the tension surface are approximately by 20% lower than surface SG values. These results correspond to the distribution of axial stresses in a beam at bending. After the shear failure, when the beam was de facto partially desintegrated to two beams with a kind of mutual friction, surface SG strain values are higher than subsurface FOS values, but the overall character is very similar.

Note that the high quality beam (Fig. 6) not only withstood static load 250 kN, but also further fatigue loading with the range 150 – 250 kN, up to almost 700000 cycles. The results indicate that surface or subsurface strain analyses can be used as a mean of informative internal quality assessment, in a similar way like e.g. in [5-7]. FOS results are consistent with SG results, their advantage, however, is a higher fatigue durability and considerably lower probability of mechanical damage, as they are located under the component surface.

Conclusions

The experimental programme of surface and subsurface strain analyses of the main frame of GRP railway bogie under bending, performed using strain gauges (SGs) and fibre optic sensors (FOSs), respectively, confirmed feasibility of the use of FOSs embedded in the component. Results obtained using the two methods were consistent. It was shown that strain analysis can be potentially used as a method of estimation of internal material quality of GRP components or latent internal defects.

Acknowledgement

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