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Design of composite linkage of bicycle frame

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Abstract: This work is focused on the design of a carbon composite linkage for full-suspension mountain bikes. An appropriate joint of composite and metal parts of the linkage was found. That was a wrapped pin joint which has high performance especially in tension because composite fibres are not cut off. In this work wrapped pin joint was designed for more types of loading, especially the compression. Main part of the work deals with design of these joints with focus on static strength, the verification of parametrically created models by static experiments, and the influence of different concepts of the wrapping and its geometry on the joint strength. The idea of the wrapped joints and knowledge of an appropriate wrapping method was used to design the composite linkage of freeride and downhill frames. Quasi-static reaction forces in rear stays were evaluated for parametrically created finite element models. According to results, a prototype was made and successfully tested. Half of weight of original Dural linkage was saved.

Keywords: Composite linkage; wrapped joint; unidirectional carbon composite; FEM; static experiment

1. Introduction

In recent years, composite materials are going to have major share in sport equipment market. This brings a lot of challenges for developers to innovate products into lighter, stiffer, more attractive and competitive. Since the late 90’s after spreading of full suspension bikes there have been a demand after lighter solutions [1,2]. The aim is composite full suspension frame. However, some share of metal parts as bearings or bearing housings is still necessary. The appropriate joint of the metal and composite parts has to be found out.

The aim of this work was the design of a bicycle frame composite linkage using all advantages of computer aided designing. In cooperation with a bicycle producer, one type of rear suspension was chosen. Using the parametrically created FEM models, the composite linkage was designed according to required loads of downhill or freeride bicycle.

Wrapped joints were investigated because of their advantage of significant in-fibre-direction strength and stiffness, non-fibre-breaking production and relatively low cost. Therefore, the most appropriate wrapping conception had to be selected

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including the failure analysis and experimental verifications of the numerical models and utilized in the linkage design.

2. Experiments and finite element models verification

2.1. Concepts of wrapping

At first, wrapped joints for tensile/compressive loading in three different conceptions (Fig.1) were designed because this type of load takes the main part in the linkage in a suspension step. Carbon fibre and epoxy matrix were chosen as the material because of its stiffness and tension strength. The samples were wrapped around threaded rods on which the smooth steel rings of different diameter were attached by wide washers and nuts. The behaviour of simple wrapped joints in tension was known from earlier research [3].

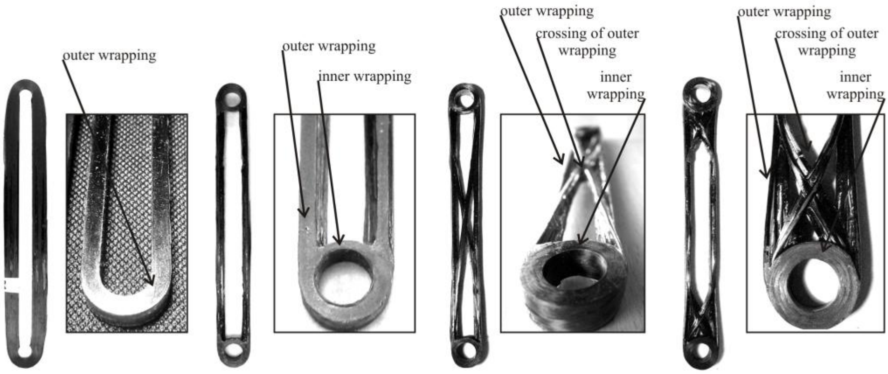

Fig. 1. Original tension sample (left) and tension/compression (simple, crossed and double-crossed) conceptions [4].

2.2. Experiments

Over the 50 experimental compressive tests were made in department laboratories. Experimental setup is obvious from Fig.2. The lower clamping head was fixed and the upper was loaded by displacement in the direction of the longitudinal axis of sample symmetry. The samples were clamped with possibility of movement in direction of loading pin axis. Reaction force and displacement were recorded. Samples were coloured white for better recognition of cracks.

2.3. Failure modes of samples

The failure of samples was different due to wrapping conception. Usually, the first cracks were initiated in the interface of the inner and the outer wrapping (Fig. 3, Fig. 4). In the case of the double-crossed conception there was dependence on the stiffness of the crossed wrapping. When the stiffness of the crossed wrapping was high a buckling of fibres in front of the crossed wrapping appeared (see Fig. 5 b).

Fig.2. Setup of compressive experiments.

2.4. Finite element models verification

Finite element models were parametrically created with focus on easy changes of any material, geometrical or load parameters. Unidirectional composite was modelled homogenously by 3D linear brick elements with defined orthotropic properties and with defined orthotropy directions (Fig.7). Loading pin was modelled as a rigid cylindrical surface and the loading was modelled by “rigid-deformable” contact. Critical forces evaluated in experiments were applied on a control node and failure indexes from results were compared with experiments.

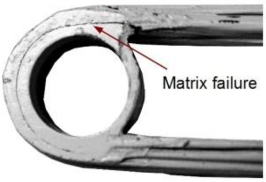

Fig.3. Simple conception matrix failure.

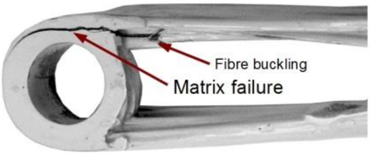

Fig.4. Crossed conception failure.

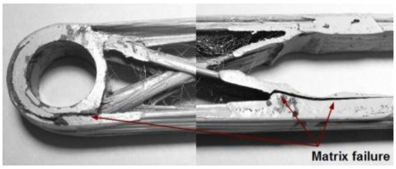

Fig.5 a). Double crossed conception.

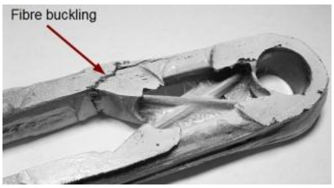

Fig.5 b). Double crossed conception.

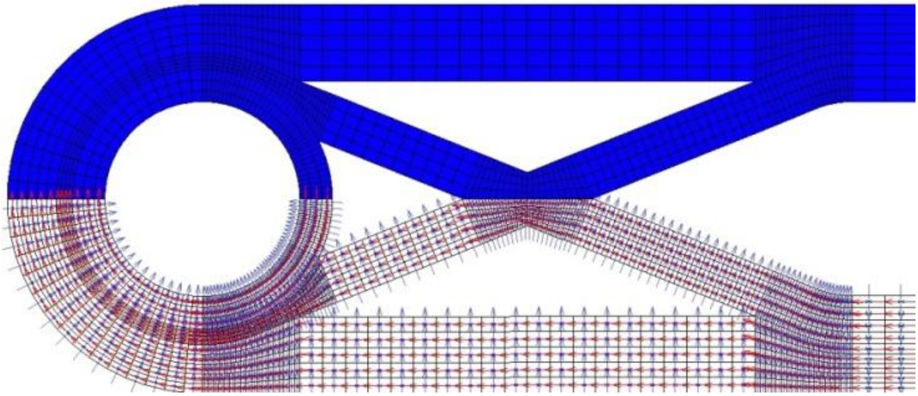

Fig.7. Directions of orthotropy in finite element model of double-crossed wrapping conception.

2.4.1. Failure criterions

For the first approach the maximum stress criterion was used. Maximum stress criterion says that there is a material failure after one of the components in lamina reaches the critical strength of material [5,6]. The used software MSC.Marc has this criterion implemented and generalized for three dimensional stress state. Results consist of six failure indexes. There was two critical indexes – the first is corresponding to compressive stress in the T' direction (3rd index) and the second is corresponding to shear stress in LT (Fig. 8) plane (6th index). Strength analysis using this criterion did not match experiments.

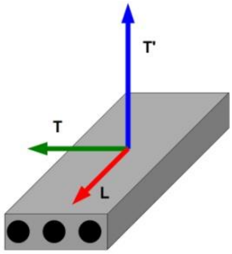

Fig.8. Directions of orthotropy in general unidirectional composite.

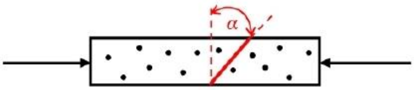

Fig.9. Mode 2 of LaRC04 criterion.

Then, the interactive LaRC04 criterion was used. It is a criterion for long-fibre unidirectional composites. It is deduced for three dimensional stress and the correction for nonlinear behaviour of composites in shear stress is integrated. The criterion recognizes six modes of failure [7,3]. Used version of LaRC04 was implemented by subroutine to MSC.Marc software with an adjustment which considers an influence of tensile stress in L direction on matrix strength (matrix reinforcement) and decrease of tensile strength in L direction if the composite is exposed to a transverse compression [3]. In this case, modes 2 (Fig.9) and 5 were critical. In mode 2, due to compression in T direction, there is a matrix failure at an angle to the plane LT'. In mode 5, due to compression in T' direction and compression in the L direction, there is a fibre buckling and matrix failure.

2.4.2. Results of finite element analysis

Results of chosen samples with failure indexes (FI) of mode 2 of LaRC04 criterion with an adjustment are shown in Fig. 10,11 and 12. Value 1 means critical value. Nodal averaging was off, values in nodes belonged to the values in integration points. The differences between numerical and experimental results were less than 20% which was, in relation to the safety coefficient, considered as satisfying.

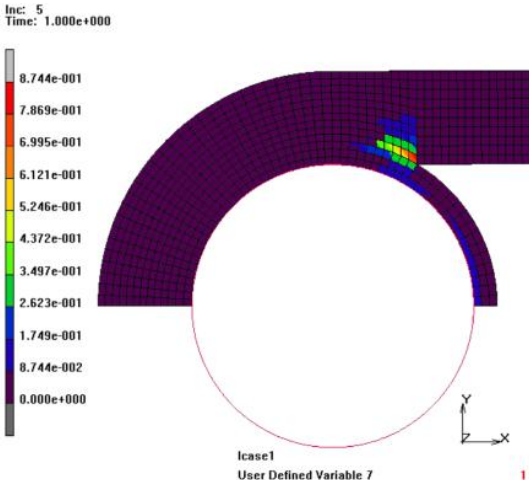

Fig.10. Simple wrapping conception. FI = 0,87.

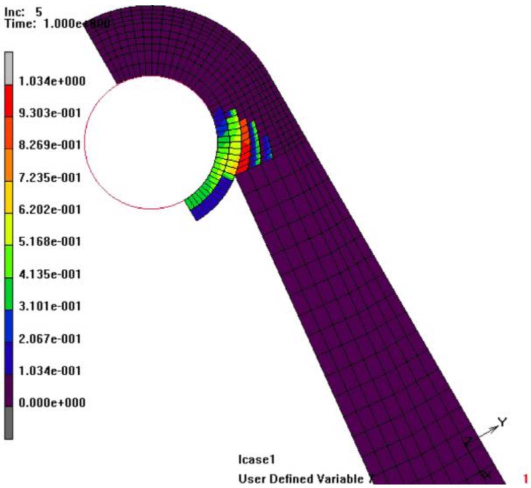

Fig.11. Crossed wrapping conception. FI = 1,03.

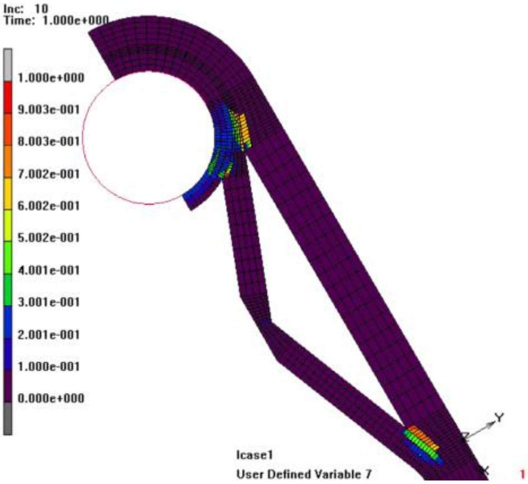

Fig.12. Double-crossed wrapping conception. FI = 1,00.

3. Application of joints analysis

The crossed wrapping conception was chosen as the most appropriate because of the highest strength. This conception was used in the part of linkage under the compressive loading (Fig.14). Angles of loading vectors change in relation to actual travel of the rear wheel, however, the character is still the compression.

Fig.13. Original Dural linkage on bicycle with 180mm rear travel.

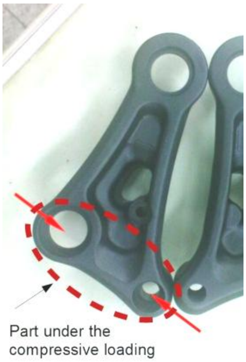

Fig.14. Linkage part under compression

Quasi-static reaction forces in the bearings during the full travel were determined (Fig. 15). Parametrically created models (e.g. Fig. 16) were created and forces and moments (taken from producer) applied with safety coefficient 2 (applied loading was 2 times higher). Diameters and positions of centres were given. Thicknesses of inner, outer and crossed wrapping were the numerical simulation parameters. The aim was the lightest solution. Critical locations are obvious from Fig. 17. Character of results was similar to the analysed samples.

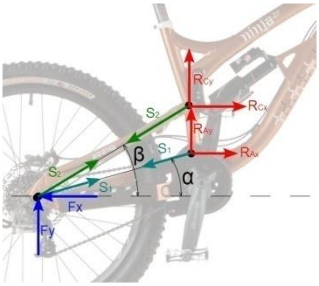

Fig.15. Joint method scheme.

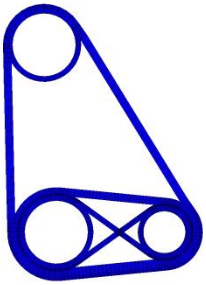

Fig.16. FEM linkage model.

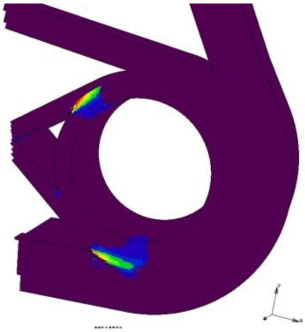

Fig.17. Critical locations according to linkage model (adjusted LaRC04, mode 2).

3.1. Prototype testing

Simple production (wrapping on pins or rods) is one of advantages of the unidirectional composite linkage. The failure (Fig. 18) during the first prototype test showed that precise saturation of all fibres by resin is very important especially in the wrapping interfaces which, among other, means to remove redundant resin after the hardening. Second prototype was convenient (Fig. 19 and 20).

Fig.18. Failure of the first prototype.

Fig.19. The second prototype on the bicycle.

The linkage was wrapped around aluminium bearing housings, therefore, all remaining original components could be used. The final composite linkage consisting of two symmetrical parts weighed 100g. The half of weight of the original Dural solution was saved. Production method combining wrapping and moulding (more design options) was proposed. Additional side stiffeners were designed (Fig. 21).

4. Conclusions

Three conceptions of the wrapped pin joint were analysed experimentally and numerically using parametrically created finite element models. The comparison of the experimental and numerical results showed that the adjusted LaRC04 failure criterion should be used instead of the maximum stress criterion. Second mode failure index of the adjusted LaRC04 criterion had critical values. Based on the experimental results, the crossed wrapping conception was chosen to be used in the linkage design. The manufacturing methods of the linkage, whose geometry parameters were designed using the parametrically created models, were proposed and used. The failure of the first prototype showed that it is very important to saturate wrapping interfaces with the epoxy resin precisely. The second prototype met the requirements. Half of the weight was saved in comparison to the original Dural linkage.

Fig.20. Shot from the on-board camera during testing of the second prototype.

Fig.21. Rendered linkage with side stiffeners.

Acknowledgements

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