Abstract

The E.U. has issued recently regulations ordering the necessity of the 40% reduction of polluting emissions and of the greenhouse gases produced by vehicles. This target is to be achieved by 2030. It is an ambitious goal asking car industry for the development of "lightweight" solutions in order to allow a consumption reduction, an overall efficiency increase and a vehicles wider sustainability: so it is necessary to optimize all mechanical systems. Since the suspension systems build up the 25% of the whole mass of a vehicle, their optimization would cause advantages both in handling and vibro-acoustic comfort. The innovative materials use, such as Carbon Fibres Reinforced Plastic (CFRP), hybrid laminate and high-damping elastomers, meet the lightness and strength requirements but they imply, at the same time, a greater complexity both in design and virtual modelling.

In this context, the aim of this thesis dissertation consisting in studying, development and testing a multi-material (carbon fibre and steel) Lower Control Arm (LCA) of a McPherson suspension for a C segment vehicle. An innovative viscoelastic material has been used to join carbon fiber with steel that works as passive constrained layer damper and adhesive simultaneously. In particular, it has been developed a specific methodology that combines both virtual and experimental procedures to face the hybridization challenges of mechanical coupling, damping and lightweight.

For these reasons, the multi-material lower control arm represents a noticeable case study in which this methodology has been applied, correlated and validated.

First of all, a multibody model of the vehicle has been made in MSC-AdamsCar and particularly of the front and rear suspension systems, in order to evaluate the forces acting on the LCA. Therefore, six main manoeuvers have been defined for evaluating the behaviour and afterwards basing the multi-material component design. Particularly, three manoeuvers concern the "special events" that are all those situations in which the arm has to assure its working in the elastic range. On the contrary, the other three manoeuvers are defined as "misuse events" that are all those situations where the arm can exceed the material elastic limit without breaking.

Subsequently, the arm CAD model has been generated through a reverse engineering activity in which it has been carried out the final geometry starting from the component 3D laser scan. In such a way, the FEM model of the original arm (also called baseline) has been created in Altair Hypermesh in order to evaluate the

overall mechanical performances and to define the design target as regards the multi-material one (also called hybrid). As far as the FEM simulations are concerned, it has been considered five load cases for evaluating: the stiffness: the behaviour for special events and misuse events, the frequency response and the longitudinal strength test.

Although the arm has been perceived as a unique prototype, a set of design constraints has been defined concerning the LCA geometry and mechanical coupling in order to be replaceable on the vehicle and compliant to standard manufacturing process. Hence, the suspension packaging analysis has been conducted and the external arm envelop has been identified as maximum design volume for the hybrid LCA. An innovative technology consisting on a calibrate Visco-Elastic Material (VEM) foil has been used to join carbon fiber with steel to satisfy the requirement of lightweight, vibration damping, stiffness and safety.

For the purpose of investigating the mechanical properties of the suspension arms materials, the experimental characterization has been conducted. As regards the viscoelastic materials, it has been evaluated two different compound in such a way to compare their stiffness, damping and adhesion properties. These tests have been performed according to the ASTM E756-05 standard for the dynamic and damping properties, and according to D5868-01, D5528, and D7905 standards for the properties of fracture toughness and strength of the adhesive joint. In addition, the VEMs have been subjected both to a test at temperature (between -20°C and 60°C) according to the SAE J 1637 and at ageing cycle of 750 h according to the IEC 60068.

As concerns the carbon fiber materials, it has been carried out the characterization of the fabric and the unidirectional CFRP following the standards ASTM D3039, D3410 and D790 for the tensile, compression and bending tests along the principal directions. Also for the steel making up the arm baseline, it has been tested according to the ASTM E8/E8m-16A.

The experimental tests results carried out on the specimens were essential for the creation of the material card, necessary to carry out the Finite Element Analysis (FEA) and to correlate the virtual models with the real behaviour.

After obtaining a very good correlation with the virtual specimen models, it has been created the FEM model for the “hybrid” arm optimization, with the main objective of reducing the mass safeguarding the stiffness and reducing vibration than the “baseline” arm. The optimization result has allowed to work out the feasible plybook in order to go on to the achievement of the hybrid component through hand lay-up and vacuum bag technologies. Finally, the mass obtained of the hybrid LCA is 1,68 kg that means 23% less than the baseline.

The last phase of the thesis has been focused on testing the two arms to obtain the frequency response and the longitudinal strength. Firstly, the experimental modal analysis has been performed and the hybrid LCA reported a sensible improvement of damping ratio of 3,5 times for each eigenmode than the baseline. Then, it has been carried out the correlation among the virtual modal analysis models and the experimental FRFs (Frequency Response Function) by comparing frequencies and MAC (Modal Assurance Criterion) index. As results, it has been obtained a very good correlation between the FRFs and a high MAC index value for both the models.

Secondly, the longitudinal strength test has been conducted to evaluate the characteristic curves of the arms. The test has been limited at 10 kN to preserve the structural integrity of the components. The test reported a stiffness difference between the arms of only 6%, and a very high correlation has also obtained with the FEM models. Subsequently, the data of experimental force and displacement have been compared with the ones obtained by the virtual models, obtaining a very good fitting for both arms with negligible differences between the curves.

In conclusion, the methodological approach applied from specimen to component has been validated by the prediction and robustness level of the FEM models and the experimental comparison done on modal analysis and strength tests. In the end, the hybrid lower control arm achieved a 23% mass reduction, a total damping increase equal to about 3,5 times and a final stiffness lower than 6% compared with the “baseline” arm values.