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Design optimization of a carbon fiber reinforced composite automotive lower arm

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ABSTRACT

Substituting composites for the metallic structures has many advantages because of the higher specific stiffness and higher specific strength of the composite materials. In this paper, we designed an automotive composite lower arm using carbon-epoxy composite materials. To optimize the stacking sequence of the composite layer, we used a micro-genetic algorithm and investigated its effects on the performances of a lower arm, such as static/buckling load capability and stiffness. To maximize the buckling load capability, we performed the design optimization with the linear perturbation eigenvalue analysis, targeting a 50% weight reduction of conventional steel lower arm. We verified again the performance of the optimized composite lower arm using the static Riks analysis technique. Finally, we found that our composite lower arm had two times higher stiffness and buckling strength compared to the conventional steel lower arm while having 50% less weight.

1. Introduction

Automotive engine emissions are recognized as a major source of air pollution [1]. In order to solve this problem, researchers have sought to reduce automotive weight to improve the automotive fuel efficiency. Many attempts have been performed to substitute the heavy metallic material of the automotive components with lighter materials such as aluminum or magnesium alloy, ultra high strength steel or fiber-reinforced plastic composites [2]. Among them, carbon fiber-reinforced composite (CFRP) material has received much attention for automotive structures because of its high specific stiffness, high specific strength and high damping capability compared to the conventional metallic materials [1,3]. Owing to these many advantages, the CFRP could reduce the weights of structural parts without any reduction of the mechanical performance [4]. However, most CFRP applications in the automotive industry have been limited only to the large exterior parts of an automobile such as the body frame, roof or doors [5]. Nowadays focus on weight-reduction of automotive components has shifted from the large exterior parts to the load-bearing parts which sustain a heavy load during driving. A lower arm is one of the suspension units, placed at the front of the passenger compartment and supports a cross member and a knuckle component. Fig. 1 shows the schematic of the lower arm structure. Since the lower arm is connected directly to the wheel, a heavy load could be conveyed to the lower arm from the impacts of a wheel. Furthermore, the lower arm should maintain not only high strength, but also high stiffness to ensure the reliability of wheel alignment. Also, since it plays an important role in reducing the vibration from the ground while driving [6], it should have high damping capability. For these reasons, CFRP may be the best alternative material for a conventional heavy steel lower arm because it has the high specific strength, high specific stiffness, and high damping capability.

In this paper, design of the composite suspension lower arm was carried out in combination with finite element analysis and design optimization. The stacking sequence of the composite layer was optimized using a micro-genetic algorithm, and its effects on the performances of lower arm, such as the static/buckling load capability and stiffness, were investigated. The design objective was to maximize the buckling load capability based on the eigenvalue evaluation with the linear perturbation method while targeting a 50% weight reduction. The performance of the designed composite lower arm, such as its static/buckling strength and stiffness, were investigated using the static Riks method based on the Tsai-Wu failure criterion.

2. Modeling of a lower arm

2.1. Geometric model

Fig. 2 depicts a conventional steel lower arm. The weight of the conventional steel lower arm is 2.15 kg excluding the rubber

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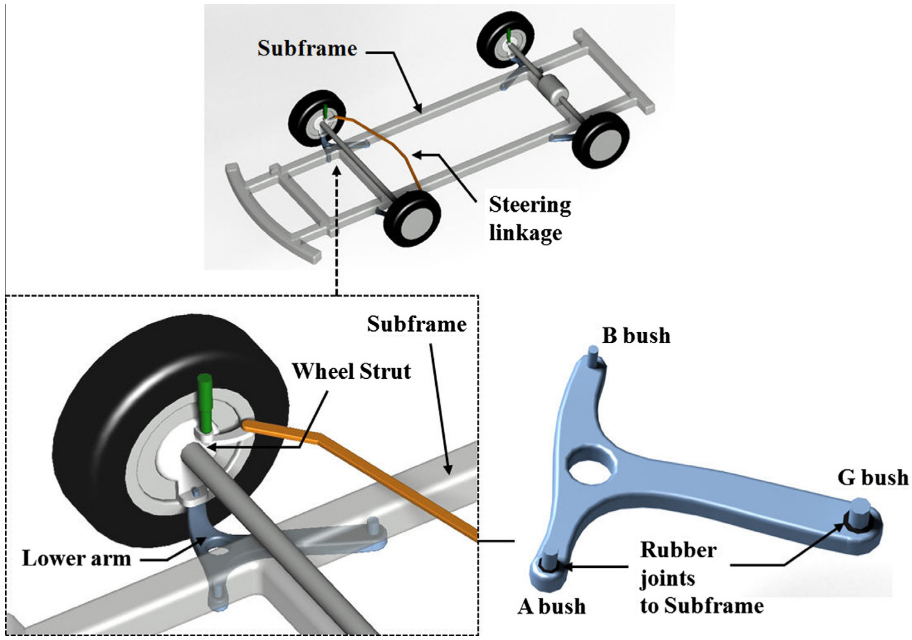

Fig. 1. The schematic of lower arm structure.

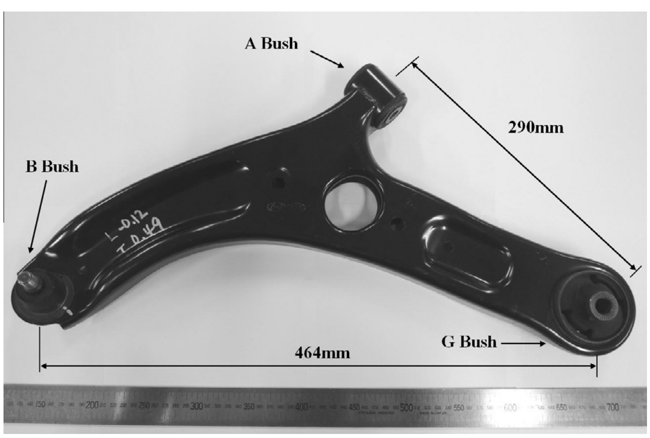

Fig. 2. The conventional steel lower arm.

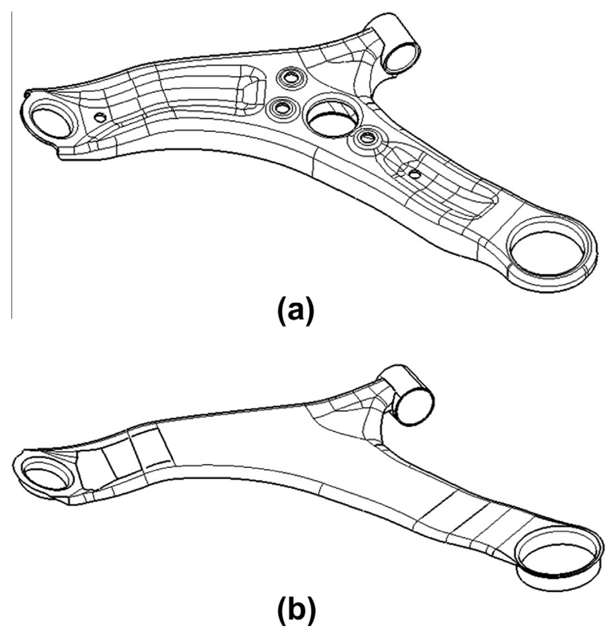

Fig. 3. Lower arm CAD models: (a) Conventional steel lower arm model. (b) Simplified composite lower arm model.

bush and connecting part. The parts of A-bush and G-bush are linked to the subframe, and the B-bush is directly connected to the knuckle of the wheel. Since the A and B links are connected to the subframe by the rubber joint (Fig. 1), they can be modeled using nonlinear spring features. The load from the wheel was imposed at the center of the B-bush. The detailed information of all boundary conditions will be described in the next section.

Fig. 3a shows a geometric model of the conventional steel lower arm, created from the CAD data of the conventional steel lower arm product. The composite lower arm model was simplified from the original design of the conventional steel lower arm in order to maintain the outline of design geometry and avoid interference with exterior geometric constraints. Also, the geometrical complexity (holes for assembly guide of bolting) was removed to save computing time in simulation. All the geometric models were generated using commercial CAD software CATIA V5 (Dassault Systems, USA). Fig. 3b shows the simplified composite lower arm model. This new model is suitable for the composite laminated lower arm structure and for the finite element analysis.

2.2. FEA model and boundary condition

Fig. 4a shows the automatically generated finite element meshes (1611 quadrilateral shell elements S4R (4-node doubly curved thin or thick shell)) using the commercial finite element software ABAQUS 6.10 (Hibbitt, Karlsson & Sorensen, USA). The element shell thickness of all of the bushes was fixed in the inside direction at 1.3 mm to meet the exterior interference constraints. The thickness of the main body is one of the variables for design optimization according to the stacking number of the composite laminate (Fig. 4b). In this work, a high strength carbon/epoxy composite (USN150, SK Chemical, Korea) was used, and its material properties are listed in Table 1.