Fatigue and Durability Based Analysis and Design of Lower Control Arm with Composite Materials

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ABSTRACT

In order to satisfy the fuel efficiency regulation and CO_2 emissions regulation, researches to reduce the weight of automobile body as well as its components have been actively carried out recently. Fatigue analysis is also becoming more important in terms of securing safety as fracture occurs even under lower than the yield stress, even if there is sufficient margin in the strength. In particular, lower control arm is a component that affects the steering safety and ride comfort in suspension system, it is essential to examine whether it satisfies the safety depending on durability. In this paper, we conducted the fatigue and durability based analysis of lower control arm with carbon fiber reinforced plastics, which is a representative composite material. For this, stress and stiffness analysis under given load conditions are performed through finite element analysis, and we verify whether it satisfies the load and stiffness conditions or not. And also, the inertia relief method for finite element analysis is utilized to simulate the static load conditions. Based on these results, the fatigue life was predicted by the stress-life method. We also applied the Smith-Watson-Topper index to account for the average stress effect.

1. INTRODUCTION

Recently, the fuel efficiency regulation and CO_2 emission regulation in vehicle industry is reinforced gradually. In that respect, carbon fiber reinforced plastics (CFRP) composite materials are extensively used in vehicle industries because of high specific strength and stiffness and low weight compared to metal materials.

Lower control arm (LCA) is a component that has a decisive effect on steering safety and ride comfort, so it is important to check safety by material changing, durability and strength which is contradictory to weight lightening. Recently, it is required to secure driving efficiency of vehicle at high speed traveling and weight lightening at the same time because of increasing awareness of consumer about ride comfort and steering safety in vehicle.

Moreover, most mechanical structures are placed under fatigue damage by repeated load. Therefore, we need to evaluate durability and analyze fatigue for securing durability of mechanical structures using CFRP materials.

Park, H. S. et al. predicted the fatigue life by evaluating the damage about life. First, fatigue tests were performed about CFRP materials by using damage mechanics. And fatigue damages are determined by using the stiffness values which are calculated from hysteresis loops, and the obtained fatigue damage curve is examined using Mao's equations and Abdelal's equations.

Kim, J. K. et al. studied durability evaluation by using inertia relief condition which is not necessary for constraint condition and optimization model considering inertia force. They performed quasi-static durability analysis using equivalent stress for durability performance. S/W Ansys workbench and MSC. Fatigue are used for performing inertia force analysis and durability test, respectively. These fatigue life analysis is evaluated by S-W-T (Smith-Watson-Topper) index.

In this paper, we studied structure analysis and durability assessment of LCA with CFRP materials. For this, we set restricted condition of LCA and the properties of CFRP material. Then we performed finite element analysis with several load conditions. We performed durability assessment with these results by adapting S-W-T index. This research paper has much meaning since it is adapted composite fiber reinforced plastics in compared with preexistence.

2. FINITE ELEMENT ANALYSIS

For analyzing the strength and durability, we use same finite element model. First, the finite element model of LCA with CFRP for strength analysis is as shown in Figure 1.

Mesh shape is composed of 2^{nd} elementary with C3D10 Mesh type and the number of elements is 99,687. For using stress distribution in shell element at fatigue analysis, we compose the surface with thin element surface.

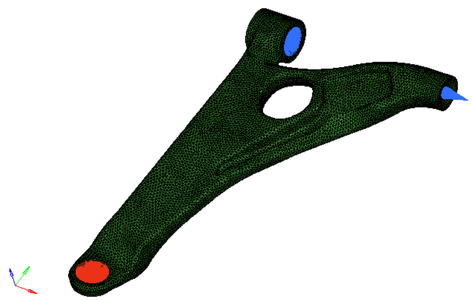

Figure 1. Finite element model of CFRP LCA

2.1. Material Properties of CFRP

CFRP is made by combining the carbon fiber and matrix. We used CFRP consisted with carbon fiber T300 of TORAY Co. and plastic resin APC-2 of HWA S. Co.. The stress-strain curve is shown in Figure 2. We selected the volume fraction of 0.68. And also, properties of carbon fiber and matrix are shown in Table 1.

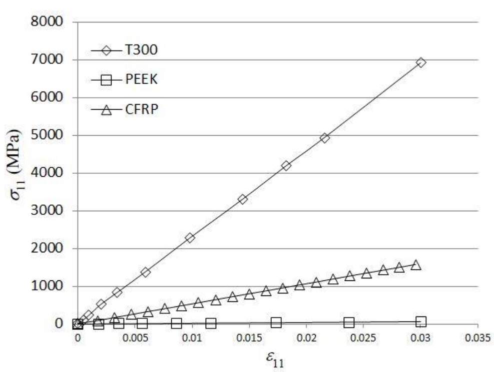

Figure 2. Stress-strain curve of carbon fiber and epoxy

Table 1. Properties of T300/PEEK

Properties \ Types	Carbon fiber	PEEK resin
Model	T300-3000	APC-2/AS4
Density[kg/m^3]	1.75X10^3	1.6X10^3
Tension strength[GPa]	3.53	2.13
Elastic modulus[GPa]	230	134
Poisson's ratio	0.2	0.38

The CFRP are assumed as uni-directional. The thickness of each layer of laminated CFRP is 2.50mm and the order of laminated layers is $[0/45/90/-45]_{2s}$. The stiffness matrix, C is shown in Eqn. (1).

$$C = \begin{bmatrix} 65422 & 22528 & 4443 & 0 & 0 & 0 \\ 22528 & 65422 & 4443 & 0 & 0 & 0 \\ 4443 & 4443 & 9539 & 0 & 0 & 0 \\ 0 & 0 & 0 & 21447 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2398.5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2398.5 \end{bmatrix} \quad (1)$$

2.2. Load Conditions and Constraint Conditions

First, the inner surface nodes of each bush were tied with the hard point of center for constraining the freedom by one-dimensional rigid element for stiffness analysis condition at strength analysis with load conditions. The hard point of front bush is constrained with three-axis which is X-, Y- and Z- axis. And there is only X- axis on rear bush. As constraining the hard point of ball joint for Z-axis, a load of 1kN is applied along the longitudinal direction (X-axis) and the lateral (Y-axis) direction.

The hard points of front and rear bush are connected with RBE3 element respectively as durability condition. And then, loads from load conditions are applied along the hard points of ball joint, front bush, rear bush respectively, and moments are applied along the front and rear bush.

A boundary condition need to satisfy more than 2.5kN/mm on X-axis and more than 50kN/mm on Y-axis in stiffness analysis. Stiffness result is measured from the displacement of the hard point at ball joint. Because the bush part is connected to vehicle body frame, and the ball joint is affected by the force from the road through the tire. In case of durability analysis, we set the safety factor of boundary condition as 1.5, so principle stresses are subjected to be smaller than 400MPa.

As performing finite element analysis using load conditions, we use inertia relief analysis method which don't need to boundary condition in this paper. Inertia relief analysis is the way to analyze the structure doing rigid body motion, it is suitable for the case that the external force is determined, but the displacement boundary condition constraining the rigid body motion isn't determined.

2.3. Results of Finite Element Analysis

As a result of stiffness analysis, it shows 2.33kN/mm on the X-axis and 52.63kN/mm on the Y-axis.

In case of durability analysis, we perform inertia relief analysis with 12 cases. These cases are having more than 10kN in average force and more than 40kN·mm in average moment. From these results, we arrange the load conditions occurring high level stress including GVW (Gross Vehicle Wight) at Table 2. Based on these results, we perform durability assessment.

Table 2. Results with durability conditions: Principle stresses

Subcase	GVW	Forward impact	Forward braking #1
Stress (MPa)	14.43	197.9	205.0
Subcase	Forward braking #3	Forward braking #4	Reverse braking #3
Stress (MPa)	268.8	361.1	304.5

3. DURABILITY ASSESSMENT

3.1. Durability Analysis

Commonly, durability analysis is divided into dynamic durability analysis and quasi-static durability analysis. In this study, quasi-static durability analysis is used to calculate the deformation rate by applying unit load on the axis which is applied dynamic load. After that we calculate dynamic stress of the system from the linear superposition concept by applying dynamic load history on system.

Therefore, the fatigue life time is computed by applying steady amplitude load history after performing static structure analysis using equivalent load.

There are two ways predicting fatigue life time. One of them is stress based approach, and the other one is strain life method. The stress-life method is usually used for the design of the case that applied stress is mainly located in the elastic region of material like a driveshaft, and the fatigue life time is long. This method is not usually adapted for the case that the fatigue life time is low and strain rate have a clear plasticity component. And also, this method displays a tendency that the notched effect is decreased as the fatigue life time is decreased. We use S-W-T index for considering average stress effect.

3.2. Results of Durability Analysis

We performed the durability factor assessment through the durability analysis criteria. The value of damage means design life time divided by available life time. The maximum value of the results are shown in table 3.

Table 3. Results of fatigue strength

	Load case	Max. damage (%)	Max. life cycle
Fatigue strength	Forward braking #3	6.456e-8	1.549e7
	Forward braking #4	8.568e-6	1.167e6
	Reverse braking #3	3.987e-7	2.508e6

4. Conclusion

We analyzed the finite element analysis for CFRP LCA under the load conditions using inertia relief method. From these results, we performed durability analysis using quasi-static durability analysis method and S-W-T index. The results show that the value of max. damage is 8.568e-6% in the case of forward braking #4. This research produced the optimal solution considering quasi-static analysis method, so after that the verification needs to use durability endurance analysis.

The research results are calculated through the stress-life method. In the future work, we will perform research through strain-life method and fracture mechanics theory and compare these results. From these results, we will check the tendency. And we will progress the optimal design about the stacking angle of laminated layers and thickness for satisfying stiffness condition and durability condition.

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