Stiffness and Durability Analysis of the Knuckle Arm for a Small Size Car

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Abstract. Traditionally, the durability performance of vehicle components and subsystem has been investigated and verified by testing physical prototypes. In this study, we performed durability analysis of the knuckle arm. Knuckle arm is a part that connects the wheel of a car to the rest of the vehicle suspension such as strut, tie rod and control arm. It is loaded by longitudinal, lateral and vertical forces. These forces are typical for handling course, in which high lateral loads occur. Such loads must be taken into account in developing process, because it affects the safety of the car. In this study, the stiffness and durability of the knuckle installed in a small size car are investigated using commercial software. Parametric analytical studies have been carried out to estimate the stiffness and fatigue life using commercial software.

Keywords: Knuckle Arm, Durability Analysis, Steering, Fatigue , Stiffness

1. INTRODUCTION

The link parts of automobile steering systems are the core elements that directly affect the vehicle performance including comfortableness, durability, and steering stability. They also are in direct relation to the general vehicle quality and operation performance. In particular, the knuckle arm functions to change the direction as desired and to combine various parts. This is of great importance when it comes to analysis of structural stability of vehicles(1). Recently, an environment-friendly technology development has become a global issue. In automobile industry as well, the importance of light-weight part development is being highlighted.

The knuckle arm is an essential component that can maximize the lightweight design of steering-link parts. Lightweight methods are divided mainly to two areas: change of the material and optimization. This study aims to seek ways of lightweight design based on the structural optimization design of the knuckle arm, and to this end, the preliminary study includes the stiffness and fatigue analysis of the knuckle arm. Based on the analysis result, the structurally weak aspects are predicted and reflected in the optimization design. The durability assessment methods include the analytic assessment method and test-based assessment method(2). In this study, only the numerical analysis is adopted.

Kweon(3) conducted a strength analysis of the knuckle arm in utilization of CAE program and a test assessment method to measure the fatigue performance through the fatigue experiment. These involves a fatigue experiment when the knuckle arm meets the requirements in the strength analysis. If the knuckle arm does not meet the fatigue performance requirement and is fractured, however, the process has to return to the initial point and repeat the fatigue experiment. In contrast, this study implements the strength analysis by means of CAE program and predicts the fatigue life based on the analytic assessment method for optimization, which reduces the number of fatigue experiments involved.

The existing studies(3~5) focused on analysis of one loading condition, and implemented the linear analysis with the effect of the joint ignored. While the vehicle is running, various types of loads are applied to the knuckle arm, and other areas of the knuckle arm are affected by the applied load. Thus, each of the effect of load should be comparatively analyzed. A linear analysis without consideration the effect of the joint might be advantageous in terms of time, but it cannot gain accurate analysis results. This study takes into consideration of about 20 different loads applied to each joint, and determines the durability and stiffness of the knuckle arm. These loadings were defined to simulate the critical loads of the service loads.

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In general, the knuckle arm is produced in a way of casting, forging, or casting and forging. The casting and forging process produces a performing product similar to the final image by means of the casting method, and then produces the finalized item through a single forging process. This enhances the tightness and strength compared to casting, and drastically reduces the initial investment and loss of materials compared to forging[1]. The knuckle used in this study is produced in the casting and forging process. In this study,

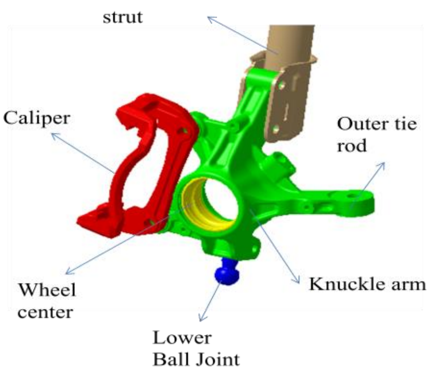

FIGURE 1. Structure of steering part

ABAQUS, MSC. Nastran and MSC. Patran are utilized to perform the stiffness and durability analyses.

2. FE MODELING OF THE KNUCKLE

The structures of steering parts are shown in Fig. 1. The modeling was done by using Hypermesh, and the knuckle was modeled with tetrahedron elements. The number of nodes and elements were 67,128 and 38,837, respectively.

The hard points connected with other parts are shown as Fig. 2. Usually the points are determined by car maker. The knuckle is connected with outer tie rod, strut lower mount, caliper, ball joint and wheel center[6]. The rigid bar elements between hard points are introduced in FE model.

The numerical analysis in this study is classified

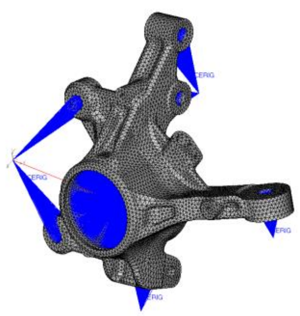

FIGURE 2. FE model of knuckle

into two categories: stiffness analysis and durability analysis. The stiffness analysis is composed of 8 loading cases, while the durability analysis is again

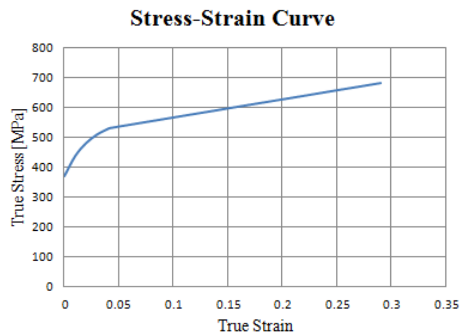

FIGURE 3. Stress-strain curve of GCD450

Table 1. Material properties of GCD450

GCD450	
Elasticity(MPa)	170,000
Density(g/cm^3)	7.10
Poisson's Ratio	0.29
Tensile Strength(MPa)	450
Yield Strength(MPa)	370

classified into non-braking case and braking case. In the durability analysis with braking condition, a special element is added to consider the braking effect.

3. STIFFNESS ANALYSIS

Various types of load applied to the wheels while the vehicle is running affect the knuckle either directly or indirectly. The stiffness is of great importance since the knuckle arm combines various parts. This study judges the stability of the knuckle arm based on the analysis of stiffness when various types of load affect the knuckle.

3.1 The material properties and measurement of stiffness

Since GCD450 is made of ductile cast iron, it has the better strength, toughness, and ductility than gray cast iron, and thus it is appropriate for the knuckle arm[7]. Material properties of GCD450 are shown in Table 1. As the criteria for assessment is equivalent plastic strain, the data after the yield point in stress-strain curve is also necessary. The stress-strain curve is represented as Fig. 3.

The knuckle used in this study is designed for a small vehicle of Z manufacturer. For the analysis of resented by Z manufacturer were applied. The stiffness assessment criteria of Z manufacturer is that in a cycle where 8 different loads occur in the car body and return to it, PEEQ needs to be met within α value. Here, PEEQ indicates the equivalent plastic strain, the permanent strain that takes place upon load. This criterion is applicable even when an external force produces plastic strain to parts.

$$\bar{\varepsilon} = \sqrt{\frac{2}{3}} e_{ij} e_{ij} \quad (1)$$

3.2 Loading conditions

The finite element model of the knuckle arm was formed by means of Hypermesh and then transformed to an ABAQUS format. The pre-processing and analysis were implemented on ABAQUS, and the resulting data was analyzed.

The degree of freedom at the central part of the knuckle was restricted. The loading condition is as follows: at the hard point, the outer tie rod, strut lower mount, and ball Joint were linked. The force was applied to the three directions of *x*, *y* and z and the moment was additionally applied to the strut lower mount in the three directions of *x*, *y* and z.

When the force was applied, the car body's weight was applied first instead of applying the specified load, and then the specified load was applied and removed. The analysis conditions of knuckle are shown as Fig. 4.

3.3 Result of the stiffness analysis

As a result of the stiffness analysis, it turned out that the 7 different strains took place in the elasticity section. In the condition where only the car body's weight was applied, the strain of the knuckle returned to the original state, which caused no permanent strain. The equivalent plastic strain in three conditions took place, among which case 1 showed the significant value of equivalent plastic strain with 0.003. That is shown in Fig. 5 and Table 2. It turned out that every result met the α value requirement presented by Z manufacturer.

4. FATIGUE ANALYSIS

The knuckle may have strength problem due to fatigue even if the stiffness analysis proved its safety. In particular, vehicle parts are likely to involve failure due to fatigue after repeated load application rather than instant loading. The knuckle arm was analyzed by means of a e – N curve based on the strain-life method(8~10).

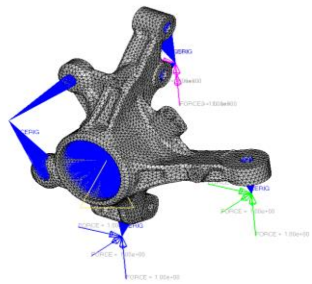

FIGURE 4. Constraint & load condition of stiffness analysis

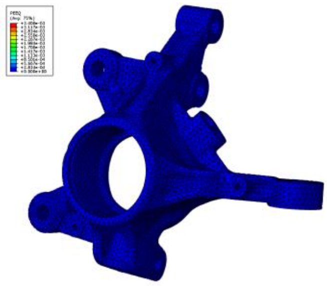

FIGURE 5. PEEQ analysis result of case 1

Table 2. PEEQ analysis results

Load case	PEEQ
Case 1	0.003
Case 2	0
Case 3	0
Case 4	0
Case 5	0.0013
Case 6	0
Case 7	0.0004
Case 8	0

The knuckle used in this study was designed for a small-size car manufactured by *Z* company. In the durability analysis, 15 loading conditions presented by Z manufacturer were applied to the knuckle. The loading conditions were divided mainly into two types - Non braking case and braking case. The former includes 9 sub loading conditions and the later 6 respectively. As for the durability assessment, 15 different loads took place from the vehicle car body weight and returned to the car load, during which the requirement of fatigue life needs to be met in each case.

4.1 Loading and boundary conditions

After the finite element model of the knuckle arm was created by using Hypermesh, the unit load was applied as a loading condition, and the initial analysis was implemented by using MSC/Nastran. Then the load history was recorded in MSC.Patran, and then the durability analysis was followed.

4.2 Non braking load case

The restriction condition for the knuckle was analyzed in the same manner with the stiffness analysis. The loading condition as well involved the application of load to the same hard points. The specified load was applied to the gross vehicle weight of the car, followed by the initial vehicle load.

4.3 Braking load case

The degree of freedom was restricted except the moment in the *y* axis at the center of the knuckle and then the moment was applied in the direction of *y*. At the hard points of the out tie rod, strut lower mount, and ball joint, the same load as in the stiffness analysis was applied.

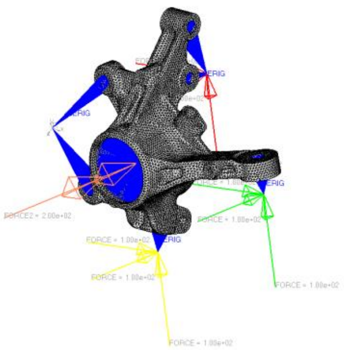

FIGURE 6. Boundary and load conditions of fatigue analysis

The caliper and wheel center were connected by means of a special element so that the shock could be absorbed. The analysis conditions of knuckle are shown as Fig. 6. The specified load in the gross vehicle weight of the car was applied, followed by the gross vehicle weight.

4.4 Result of the durability analysis

As a result of the fatigue analysis on the non braking load case, all of the 9 items turned out to have a longer lifespan than that required by Z manufacturer. The fatigue life of items except two was infinite, and the shortest life was 635,000 cycles in the 9th case. That is shown in Fig. 7.

In the fatigue analysis on the braking load case, 6 items turned out to have a longer lifespan than the targeted cycle required by Z manufacturer. The fatigue life of items except three was infinite, and the shortest life was 6,050,000 cycles in the 12th case. That is shown in Fig. 8.

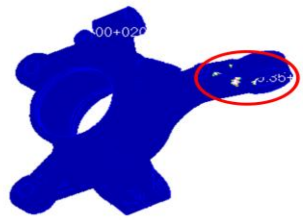

FIGURE 7. Fatigue analysis result of case 9 at nonbraking load case

FIGURE 8. Fatigue analysis result of case12 at braking load case

5. CONCLUSIONS

Based on the stiffness analysis and fatigue analysis on the knuckle arm used in a small car in different loading conditions, the presented conclusion is follows:
(1) The maximum equivalent plastic strain in the stiffness analysis was 0.003, which was below the limit of α value specified by *Z* car maker.
(2) The stiffness analysis result shows that although there was some difference among the loading conditions, most of the strut lower mount parts involved the largest equivalent plastic strain. Thus, this is to be taken into consideration in future structural optimization design.
(3) The minimum life in the fatigue analysis was 635,000 cycles, which was below the limit specified by *Z* car maker.
(4) A fatigue failure occurred after 635,000 cycles in the joint of the outer tie rod, which indicates that it met the cycle requirement presented by *Z* manufacturer, but it needs to be strengthened in the optimization design to secure safety.

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