



Fatigue analysis of an automotive steering link

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ABSTRACT

Fatigue analysis was performed in order to prevent fatigue failures and estimate the fatigue life of an automotive steering link, which is very critical for vehicle safety. Uniaxial specimens taken from the link tube were used for the monotonic tensile test and strain-controlled low-cycle fatigue test, which resulted in the monotonic and cyclic properties of the link material. Finite element method was employed to determine local stress and strain distributions of the link. The experimental strains at the critical locations were measured by using strain-gages in order to verify the accuracy of the finite element analysis results. Calculated local strains at the curved region of the link were close to the experimental strains within a difference of 8%. A carbon tube steel of STKM12C for the steering link exhibited cyclic softening behavior. Cyclic yield strength was about 25% lower than the monotonic yield strength. As expected by the finite element stress analysis, cracking occurred at the curved region of the tubular steering link rod and propagated circumferentially to the opposite side of the link rod, resulting in the final fracture.

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1. Introduction

Automotive components are subjected to the cyclic loading during the operation, which leads to fatigue crack and propagation of the crack due to the local fatigue damage. The fatigue failure prevents the components from functioning properly, and causes the critical problems in vehicle safety [1]. Therefore, in order to secure the automotive components against fatigue failures, durability test of the assembly of the components has been performed in the automotive industries. Recently, at the early stage of the vehicle development, fatigue design and durability analysis are applied for the chassis systems such as power transmission, suspension, steering, and brake which are critically important for the vehicle safety [2–4].

A link in the steering system is a component which transmits steering forces between Pittman arm in the steering shaft and a steering arm in the knuckle. The link as shown in Fig. 1 consists of link rod, and ball joints. In this paper, in order to ensure the reliability of the link assembly in the steering system, the fatigue analysis of the link was performed by incorporating the finite element stress analysis of the link assembly and the low-cycle fatigue test of the link material. Predicted fatigue life of the link was compared to the experimentally determined fatigue life to evaluate the validity and accuracy of the fatigue analysis.

2. Material characterizations

2.1. Monotonic properties

The link was made of 0.12% carbon steel (STKM12C) used for the structural pipe and tube. To investigate the monotonic tensile properties of the material, flat specimens, 3 mm thick and 8 mm wide, were taken from the link. Hydraulic material

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Fig. 1. Link assembly in steering system.

Table 1

Mechanical properties of STKM12C steel

Elastic modulus, E (GPa)	207
Yield strength, σ_{ys} (MPa)	485
Tensile strength, σ_u (MPa)	535
Fracture strain, ϵ_f	25.8
Strain hardening exponent, n	0.1225
Strength coefficient, K (MPa)	942.9

testing system with 100 kN capacity was employed for the tensile test using the displacement control mode at the loading rate of 0.2 mm/min.

Mechanical properties of the material are listed in Table 1. Yield strength of 0.2% offset and tensile strength were 485 MPa, and 535 MPa, respectively. Strength coefficient, K and strain hardening exponent, n were determined from the regression analysis, resulting in 942.9 MPa and 0.1225, respectively. A mathematical representation of the monotonic stress–strain relationship can be written as [1]

$$\epsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K} \right)^{1/n} \quad (1)$$

2.2. Low-cycle fatigue properties

In order to evaluate the fatigue life of a component, material response due to the cyclic loading should be characterized. The cyclic material properties can be obtained by the standard test specimen and procedure according to the ASTM standard [5]. Since the fatigue life of the link was to be estimated in this research, low-cycle fatigue test specimens of a cylindrical shape with 5 mm diameter were taken from the link rod, and strain-controlled fatigue tests were performed.

From the fatigue tests with different levels of the constant strain amplitude, a cyclic stress–strain curve can be obtained as follows [1]:

$$\frac{\Delta\epsilon}{2} = \frac{\Delta\sigma}{2E} + \left(\frac{\Delta\sigma}{2K'} \right)^{1/n'} \quad (2)$$

where K' and n' are cyclic strength coefficient, and cyclic strain hardening exponent, respectively. From the reversals to failure, $2N_f$ at the applied strain amplitude, fatigue life equation can be represented as follows:

$$\frac{\Delta\epsilon}{2} = \frac{\Delta\epsilon_e}{2} + \frac{\Delta\epsilon_p}{2} = \frac{\sigma'_f}{E} (2N_f)^b + \epsilon'_f (2N_f)^c \quad (3)$$

The low-cycle fatigue properties of σ'_f , b , ϵ'_f , in Eq. (3) were determined from the log–log linear regression analysis.

Total number of 10 specimens with 7 different levels of strain amplitude was used for the fatigue test. The low-cycle fatigue properties are listed in Table 2. The cyclic softening behavior can be observed clearly in Fig. 2. The cyclic yield strength of the STKM12C steel was approximately 25% lower than the monotonic yield strength. Strain-life curves based on Eq. (3) are plotted in Figs. 3 and 4.

3. Stress analysis

Fatigue lives of mechanical and structural components depend on the material properties and applied loads on the components. Fatigue cracking occurs at the localized vulnerable regions. Therefore, in order to analyze failure causes and to esti-

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