OPTIMUM PERFORMANCE EVALUTION OF REINFORCED SPRING SUSPENSION SYSTEM USING NONLINEAR ANALYSIS METHOD

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ABSTRACT: Air springs are prevalently used as suspension in train. However, air springs are seldom used in automobiles where they improve stability and comfort by enhancing the impact-relief, breaking, and cornering performance. Thus, this study proposed a new method to analyze air springs and obtained some reliable design parameter which can be utilized in vehicle suspension system in contrast to conventional method. Among air spring types of suspension, this study focused on sleeve type of air spring as an analysis model since it has potential for ameliorating the quality of automobiles, specifically in its stability and comfort improvement by decreasing the shock through rubber sleeve. As a methodology, this study used MARC, as a nonlinear finite element analysis program, in order to find out maximum stress and maximum strain depending on reinforcement cord's angle variation in sleeves. The properties were found through uniaxial tension and pure shear test, and they were developed using Ogden·Foam which is an input program of MARC. As a result, the internal maximum stresses and deformation according to the changes of cord angle are obtained. Also, the results showed that the Young's modulus becomes smaller, then maximum stresses decrease. It is believed that these studies can be contributed in automobile suspension system.

Keywords*: Suspension Spring, Rubber Characteristics, Reinforcement Cord, Nonlinear Mechanics, Finite Element Analysis, Optimum Evaluation*

1. INTRODUCTION

Air spring is widely used as a secondary suspension system in railroad car. However, it has rarely been employed as a part in automobiles. There are many studies concerning on the use of air springs in railcars, and they are using in a variety of forms and commercial railroad car.

The general application for the passenger car is an anti-vibration material, and it contributes riding comfort as a suspension in the initial stage. The advantages of air spring as a secondary device are shock-resistant performance, stability and comfort. In addition, it can increase the braking performance on the ground, reliability preventing of slant, and riding comfort preventing of shake, and it prevents excessive roll and pitch motion.

The major components of the air spring are upper plate, lower plate and rubber sleeve. The tension of the air load allays vibration to improve stability and riding comfort. Ru bber sleeve is the composite material, which is made up of combination of rubber and Nylon, and the chara cteristics of performance are varied according to the sh ape of rubber sleeve and the angle of reinforcement c o r d . As an automotive high-performance hydraulic suspension, Kim *et al* [1] improved damping performance by modifying the shape of orifice, and Lee *et al* [2] analyzed the deformation of diaphragm type air springs imposing cord angle. As the one of newest research papers, Kim *et al* [3] fulfilled Mullins FEM analysis and optimized rubber characteristics through the professional software for the passenger car.

In this study, the distribution of stresses and the deformation for rubber sleeve composite material are analyzed using nonlinear finite element method using the commercial MARC® (MSC software Corporation, U.S.A.) software. Maximum stresses and deformation according to the characters of rubber sleeve and the changes of cord angle was computed using by numeric analysis method.

2. Materials and Methods

2. 1 Geometry of sleeve type air spring

Fig. 1 shows geometry of air spring constructed by rubber sleeve with upper plate and lower plate to have a function of air spring suspension. A rubber sleeve was manufactured using modified blade core process at Bansuk Industry. In this study the cord angle of rubber sleeve is the most important factor to estimate behavior of fatigue life on the stress and deformation of air spring suspension.

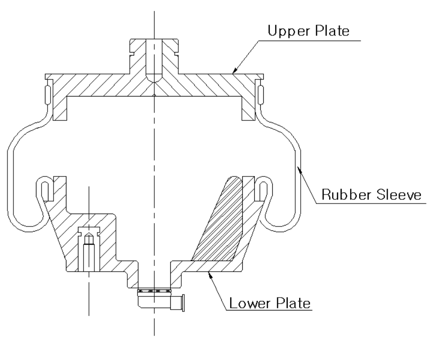


Fig. 1 Geometry of air spring with rubber sleeve

2. 2 Experimental test of rubber

The experiment of the uniaxial tension test and the pure shear test were performed to find material properties of rubber sleeve and Nylon. The uniaxial tension test was carried out by the KS M6518 [4] and ASTM D412 [5] protocol and UTM (Instron Corp., U.S.A.) material test machine was used with range of 500N load cell. The specimen used for the test was dumbbell type No.3 of KS standard as shown in Fig. 2. The speed of test on specimen was 500mm/min and the deformation rate was within 500%. Fig. 3 shows an experimental result of uniaxial tension test.

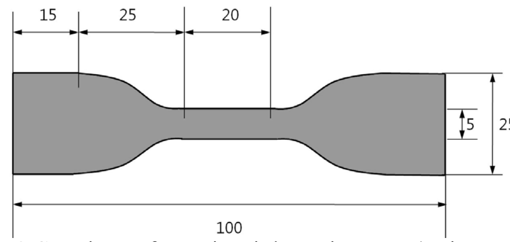


Fig. 2 Specimen for uni-axial tension test (unit: mm)

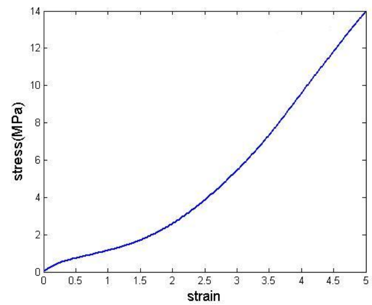


Fig. 3 Result of uni-axial tension test

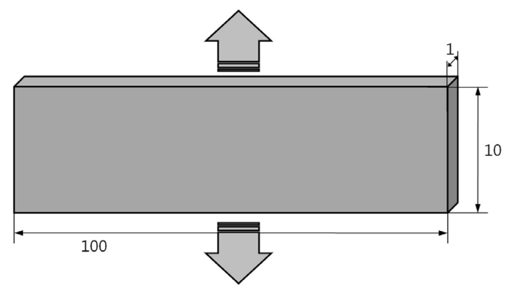


Fig. 4 Specimen for the pure shear test (unit: mm)

The specimen for the pure shear test method was not provided from KS standard and ASTM regulation, so similar test of specimen for the pure shear deformation would be created and fulfilled. While elasticity was affected to the pure shear test, the surfaces of the specimen's sides were not changed to pure shear deformation mode. However, if the lateral deformation was 10 times more than vertical deformation, there were no effects on the stress-deformation curves. Therefore, the specimen with length of 100 mm, height of 10 mm, thickness of 1mm in Fig. 4, and a 500N range tester with the speed of 500 mm/min was used in this research. A test results is shown in Fig. 5.

2. 3 Tensile test of reinforcement cord of Nylon

Reinforcement cord similar to a Nylon textile was adhered to the middle of rubber sleeve. Cut strip method of KS K0860 [6] was adopted for uniaxial tension test of Nylon. The adhesion angle of reinforcement cord, which is main variables of air spring suspension, was tested for 35, 45, and 55 degree of the central axis. The value of Young's m odulus (E) was 135.23 MPa for 35degree, 145.55 MPa for 45 degree, and 138.78 MPa for 55 degree, respectively (Fig. 6).

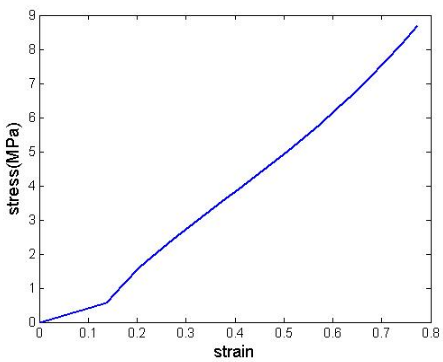


Fig. 5 Result of the pure shear test

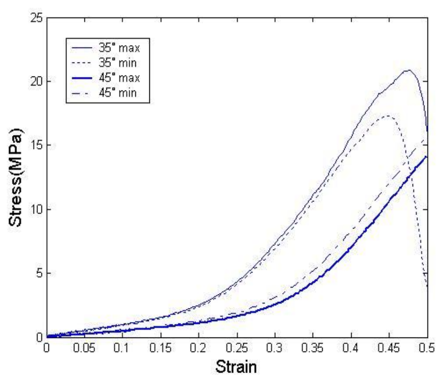


Fig. 6 Results of uni-axial tension test for Nylon

3. Finite Element Analysis

3.1 Modeling of rubber sleeve

An axisymmetric two dimensional geometry of air spring was constructed using CATIA (Dassault Systems, V5, France), and then the geometry was imported to nonlinear finite element analysis code MARC®. Fig. 7 shows two dimensional finite element model with lower and upper plate of air spring. The composite/gasket 152 four node element type [7-8] and follower force method were applied for rubber sleeve part and internal pressure was 2 bar.

Since the motion characteristics of an elastic body can be represented by its nonlinear, incompressible and large deformation, the motion characteristics can be written as the Equation (1), (2) and (3) of transformative energy.

$$W = \varpi(\lambda_1) + \varpi(\lambda_2) + \varpi(\lambda_3) \quad (1)$$

$$W = \sum_{n=1}^{N} \frac{\mu_n}{\alpha_n} (\lambda_1^{\alpha_n} + \lambda_2^{\alpha_n} + \lambda_3^{\alpha_n} - 3) \quad (2)$$

$$W = \tfrac{1}{2}\mu_1(\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3) - \tfrac{1}{2}\mu_2(\lambda_1^{-2} + \lambda_2^{-2} + \lambda_3^{-2} - 3) \quad (3)$$

Where, μ_n and α_n is a material constant, which can be found from the stress-strain curves from the result of tensile test, compression tests and shear tests. In this study, nonlinear coefficient of the rubber was chosen by curve fitting method of compression and shear test of stress-strain. Material constant of the pure shear test with rubber nonlinear constant tension was obtained by trinomial Ogden function [9]. Table 1 shows the material constant and bulk modulus acquired from the MARC®. The Young's modulus of Nylon was obtained by tensile test, and the Poisson's ratio was 0.3.

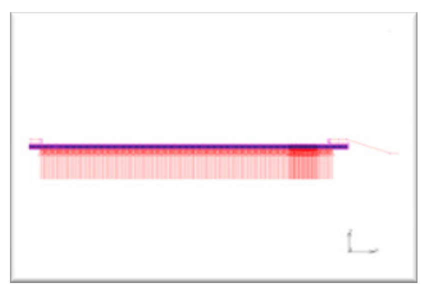


Fig. 7 Axisymmetric finite element model

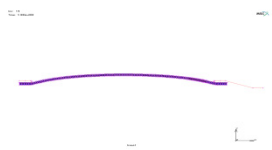
Table 1 Material properties of rubber

Number of term	3		
Bulk modulus	12607.5		
Error rate	1.725		
Moduli	-0.360573	-0.386998	-0.270914
Exponents	3.20111	-6.88181	-4.52371

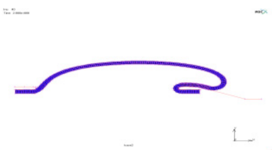
3.2 Determination of analysis steps

The air spring analysis classified as 4 steps. In first step, the internal pressure was delivered in the air spring's initial stage. In second step, the position of upper plate was shifted. In third step, the internal pressure was to remove. In the last step, the position of upper plate was shifted more and the internal pressure was applied again. These steps mean the production stages of air spring until third step, and the last 4th step was the application stage.

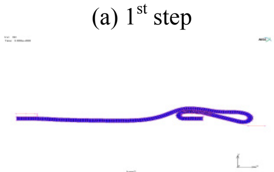
The position of the upper plate of the air spring in second step was 64 mm from the initial position. In the last step, it moved 16 mm from the second position farther. These four steps of air spring deformation were illustrated in Fig. 8.



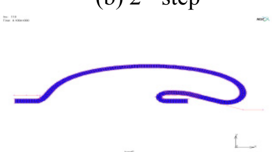
(a) 1st step



(b) 2nd step



(c) 3rd step



(d) 4th step

Fig. 8 Deformation of air spring according to the analysis steps

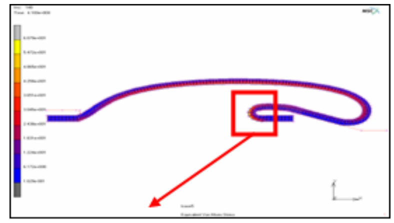
4. Results and Discussion of the Analysis

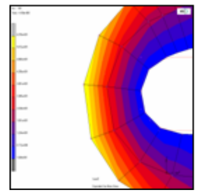
4.1 Maximum stress

According to the position variation of maximum stress of rubber sleeve in conformity to the angle of reinforcement cord and analysis steps, the maximum stress transformation was analyzed and examined.

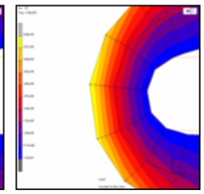
When air spring stays in the 4th analysis step, the maximum stress occurred in the vicinity of the commissural line of lower plate, where rubber sleeve had the largest deformation. From these result, the fatigued pos ition can be predicted. The position of maximum stress and the distribution of stress according to the angle of cord are showed in Fig. 9.

As the angle of cord was larger, the Young's Modulus and the maximum stress tended to reduce. Fig. 10 shows that deformative variations of von-Mises stress at a node point of maximum stress in analysis step.

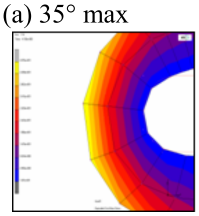




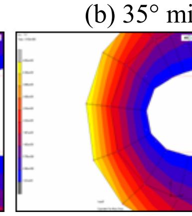
(a) 35° max



(b) 35° min



(c) 45° max



(d) 45° min

Fig. 9 The stress distribution according to cord angle

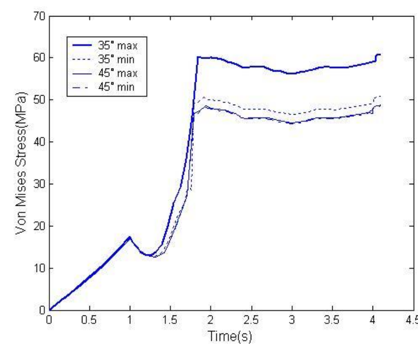
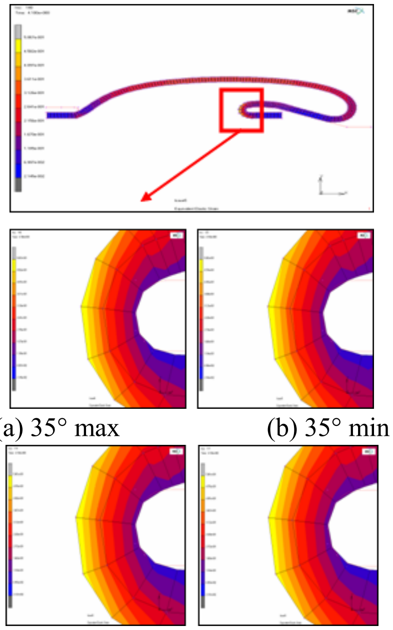


Fig. 10 Von-Mises stresses by analysis procedure on the maximum stress nodes

4.2 Maximum strain

The maximum strain of air spring can be found at the last step where the maximum stress occurs. As the maximum stress and the angle of cord become larger, the maximum strain became smaller. However the discrepancy of maximum strain and maximum stress was extremely small value. Fig. 11 shows the section of maximum strain and distribution of strain by the angle of cord. Table 2 shows the Young's Modulus from the angle of cord and maximum stress-strain at 35 and 45 degree. Fig. 12 shows that variations of the elastic strain by the analysis procedure at the node of the maximum strain occurred.



(a) 35° max (b) 35° min

(c) 45° max (d) 45° min

Fig. 11 The section of maximum strain and the distribution according to the cord angle

Table 2 Effects of Cord Parameters

Cord Angle	35° max	35° min	45° max	45° min
Young's Modulus(MPa)	118	99.82	96.03	95.63
Maximum stress(MPa)	60.79	50.84	48.76	48.58
Maximum strain	0.5067	0.5063	0.5061	0.5061

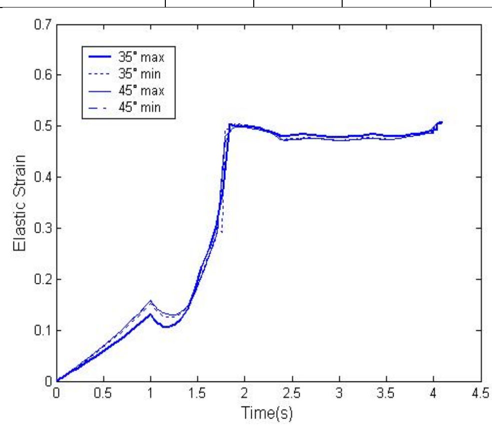


Fig. 12 The variation of elastic strain by analysis procedure at the maximum strain node

The properties were found through uniaxial tension and pure shear test, and they were developed using Ogden·Foam which is an input program of MARC. As a result, the internal maximum stresses and deformation according to the changes of cord angle are obtained. Also, the results showed that the Young's modulus becomes smaller, then maximum stresses decrease. It is believed that these studies can be contributed in automobile suspension system.

5. Conclusion

In this study, nonlinear finite element analysis was performed according to the variation of the rubber sleeve cord angles. By comparing and analyzing the angle of cord from maximum stress and strain, the simulation results gave following conclusions.

Analysis result proved that the elasticity and the maximum stress of the rubber sleeve tend to decrease as the reinforcement cord angle increase. The simulation confirmed that the maximum stress occurs at the same section of maximum deformation around the commissural line of lower plate and rubber sleeve. The region of maximum strain and maximum stress was the same. However it happened, stress increases gradually in accordance with reinforcement cord angle larger, yet strain has a tendency to decrease on the contrary.

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