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Numerical evaluation of time-dependent sagging for low density polyurethane foams to apply the long-term driving comfort on the seat cushion design

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ABSTRACT

Car seat's bearing capacity, after a person takes a seat, is time dependent and tend to harden with increased time. Hardening of seat results from viscoelasticity of seat's foam pad, and has a great effect on a person's seating comfort in a long term driving mode. As such, evaluation of changes to bearing capacity is an important design factor that must be considered at the time of the seat design, and need to be evaluated quantitatively. This study intends to apply numerical analysis for quantitative evaluation of the changes to bearing capacity of seat cushions during a long term driving, and evaluate based on different materials of seat foam pads to be used as a reference material during the design. Car seat's comfort functions are divided into static comfort, evaluated in a time domain, and dynamic comfort, evaluated in a vibrating domain. However, as this study only intends to evaluate the seat cushion's hardening effects during a long term driving, we only evaluated the static comfort in a time domain. We assumed the long term driving to be two hours, quantified the hardening level to an amount of sagging, and evaluated three types of low density polyurethane foams with different material characteristics. We applied the analysis method used and verified in the previous research phase to numerically evaluate the amount of sagging depending on the seating time, and tested the foam pad's static compressive behavior and viscoelasticity behavior to acquire data on material's characteristic. In order to consider body's seating position, we used HPM-1 dummy model provided by ESI's PAM-COMFORT (finite-element analysis program exclusively for seat), and compared the amount of sagging. We were able to predict the amount of sagging of each material from the analysis results and confirmed noticeable differences.

1. Introduction

Among automotive technologies, research related to sensibility design are widening its territory to fulfill customer demands (Park et al., 2006; Jang et al., 2001). Sensibility design focuses on passenger's continuous comfort, many environmental factors (vibration, noise, air condition, temperature, humidity, etc.) must be considered. In order to induce body comfort, passenger's condition (body size, propensity, trend, psychology, driving environment, habit, etc.) must be reflected, which may result in various standards. Specifically, as seat interacts with passenger the most, there are multiple design factors that must be reflected during sensibility design. Moreover, seat comfort is a subjective evaluation and sensibility design is even more difficult (Griffin, 1990; Park et al., 2002; Lee et al., 2007).

Sensibility design research on seat has been focused on quantification of comfort and setting standards to apply during designing. In order to quantify seat comfort and set standards, ergonomically focused definition is needed. Comfort has been defined as a status where passenger is not discomforted, and many tests have been done to define a standard for a non-

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discomforted status (Oborne and Clarke, 1973; Griffin, 1995). Establishing quantifiable discomfort requires analysis of mechanical behavior between seat and the body during the passenger's seating process. Thus, as a characteristic of interaction between seat and the body, research on body pressure, reaction, vibration and posture changes are being conducted (Kamp, 2012; Andreoni et al., 2002; Kamijo et al., 1982; Hertzberg, 1972; Kohara and Sugi, 1972; Date, 1988; Ozturk and Anlas, 2011; van Niekerk et al., 2003; Verver et al., 2005; van der Westhuizen and van Niekerk, 2006; Ippili et al., 2008; Yoo et al., 2006; Siefert et al., 2008; Vincent et al., 2012). These characteristics of mechanical behavior changes over time from the initial seating status. This effects the body's fatigue accumulating over time, and plays an important role in evaluating comfort level during a long term driving (Park et al., 2014). Characteristic of the time dependent mechanical behavior results from nonlinear/large deformation characteristic of polymer materials, excluding metallic materials of seat structure, and especially from viscoelasticity (Blair et al., 1998; Cavender and Kineklaar, 1996). Basic reference could be established reflecting comfort level during a long term driving by analyzing/evaluating material's time dependent characteristics from experimental/analytical perspective; however, technology to analyze/predict behavior on seat material is lacking (Ebe and Griffin, 2001). In order to resolve these issues, experimental/analytical methods for predicting mechanical behavior of seat over time must be developed. Moreover, a guideline to evaluate the effectiveness of materials in the designing stage based on basic data in increasing comfort need to be presented.

Shen et al. (Shen and Parsons, 1997; Shen and Vertiz, 1997) asserted that the factor with the most effect from the various factors that impedes comfort, determine the comfort level, and evaluation of comfort must be done over time. Namely, continuation of comfort over time is important, not just during the initial seating status. Moreover, seat's comfort has been classified as initial comfort, at the time of sitting, and transition comfort, during a long term driving, and dynamic comfort, resulting from vibration. Grujicic et al. (Grujicic et al., 2009) performed seating analysis using material data from foam material's stress-relaxation test, but only considered stress-relaxation phenomena during a short sitting time, not over time. Brody et al. (Briody et al., 2012) verified using foam material's viscoelasticity model, but only estimated viscoelasticity behavior of specimen model, not evaluating the entire seat. Oh et al. (Oh et al., 2015) numerically demonstrated the time dependent characteristics of foam material, presented material modeling method to apply to explicit fixed-element analysis, and verified effectiveness by applying to seat model.

This study applied the research process from the previous stages (Oh et al., 2015) to numerically quantify the changes in bearing capacity occurring during a long term driving, and analyze correlation between changes to bearing capacity and comfort on seat cushions with different stiffness. Using seat foam pad, we evaluated the changes to bearing capacity at the initial seating and after two hours of driving, and in order to evaluate the driver's support level after a long term driving, we estimated the amount of sagging over time. In order to do this, 3 types of low-density polyurethane foams, typically used in car seats, were selected, and tests to evaluate the characteristic of materials were performed. Loading-unloading test, to eliminate the load after compression of foam specimen, was performed and stress-relaxation level were measured for two hours after compression over specified displacement. PAM-COMFORT, analysis program exclusively for seat, were used for analysis, and applied time dependent material data conversion process. Additionally, evaluation of seating analysis and seating process was performed using HPM-1 model.

2. Material tests of low density polyurethane foams

J.D. Power added a category for hardening of seat after a long term driving in evaluating long-term reliability to IQS-4 (Initial Quality Study) for evaluating new car quality (IQS-4). Sagging phenomenon during long term driving induces hardening of seats, and may increase the driver's fatigue by causing changes different from the support experienced during the initial seating stage. The greater the amount of sagging means the greater changes to the characteristic of material, and hardening of the seat hinders the blood circulation by pressuring the hip area and causes pain or discomfort (Bader et al., 1986; Chow and Odell, 1978). Two material tests were performed to evaluate the time dependent characteristics of materials and gather material data to apply in analysis. Compressible loading-unloading tests were performed to evaluate the compression behavior of foam material at quasi-static status, and stress-relaxation tests, one of the viscoelasticity tests, were performed to evaluate the characteristics over time.

2.1. Loading-unloading test

To evaluate the compression behaviors of the seat foams, loading-unloading tests were performed on seat foams of three different vehicles by compressing the seat foams and releasing the loads. The dimensions of the seat foam specimens were 70 × 70 × 30 mm and the foam pad densities of each vehicle are listed in Table 1. The tests were performed at a room temperature (20 ± 5 °C). The loading-unloading tests were done by compressing to 75% strain and releasing the loads. The test speed was set at 5 mm/min for all three models. A universal testing machine (INSTRON 5882) and a compression jig 200 mm in diameter were used for the tests. The test results of each vehicle's seat foam are shown in Fig. 1. Stiffness was compared through examination of the stress-strain curves of the three vehicles: Foam A had the largest value, followed by Foam B and Foam C.

2.2. Stress relaxation test

The support felt after prolonged driving corresponds to the comfort experienced by the human body as time passes; the support decreases as the elastic force of the seat foam deteriorates. The amount of sagging is the degree of sagging compared with the amount of initial compression of the foam pads after prolonged driving and can be obtained by subtracting the amount of initial compressions from the total compression of the seat foam pads. The driving time was assumed to be 2 h. Thus, stress relaxation tests were conducted to consider the material characteristics of foam pads as time was varied. The stress relaxation tests were performed by maintaining constant compression thickness for 2 h, as shown in Fig. 2(b). As shown in Fig. 2(a), the compression thickness obtained when loads of 5 kg were applied to samples with dimensions of 70 × 70 × 30 mm was set as the compression thickness condition. Table 2 shows the compression thickness of each foam material. After maintaining the compression thickness on the specimens for 2 h, stress relaxation, in which the stress decreased as time passed, was observed and the results of the stress

Table 1
Density of foam specimens.

	Density (kg/mm^3)
Foam A	7.6×10^{-8}
Foam B	7.0×10^{-8}
Foam C	6.6×10^{-8}

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