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Wrinkle prediction of seat cover considering cyclic loading-unloading with viscoelastic characteristics

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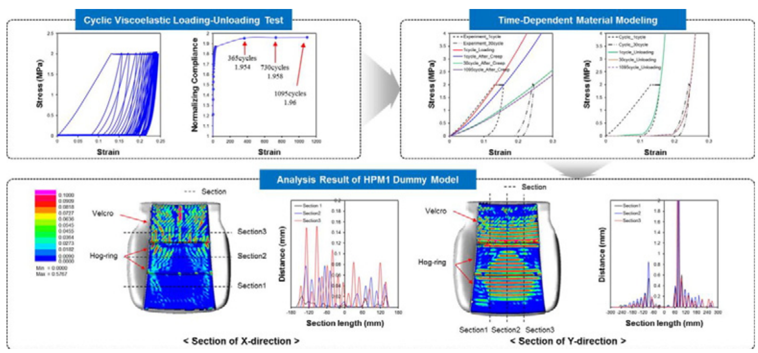
HIGHLIGHTS

- This study predicts the wrinkling of seat covers created by repeated loading–unloading and long-term driving conditions.
- To predict wrinkling, this paper describes a numerical analysis process and material test methods.
- To perform the seating simulation, PAM-COMFORT, a commercial software package for seat modeling, is used
- The numerical process is applied to a seat module with an HPM1 dummy, and quantitative wrinkle deformation is predicted.

GRAPHICAL ABSTRACT



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ABSTRACT

The purpose of this study is to predict the wrinkling of leather seat covers created by repeated loading–unloading conditions and long-term driving conditions. To predict wrinkling, this paper describes a numerical analysis process and material test methods. Viscoelasticity is considered to express the time-dependent deformation of the seat cover and a leather material is selected. To evaluate the viscoelastic behavior of leather seat covers in accordance with time and the number of times being seated, cyclic tests are conducted using leather specimens of a strip type. In the cyclic tests, one cycle consisted of loading–creep–unloading conditions; the viscoelastic (creep) time is 1 h, and the total repeated number is 60. To perform the seating simulation, PAM-COMFORT, a commercial software package for seat modeling, is used, and permanent deformation of the seat cover is predicted. It can be difficult to predict viscoelasticity using explicit code. As such, a material modeling and evaluation process is suggested. Test results obtained using a model construct are compared with experimental test results with good agreement. The numerical process is then applied to a seat module with an HPM1 dummy model, and quantitative wrinkle deformation is predicted. The proposed process was used to determine the material properties that had deteriorated due to the viscoelastic characteristics of the seat covers. The viscoelastic effects on wrinkle occurrence were confirmed analytically by applying these properties to the seat modules.

1. Introduction

Recently in automotive design, research has focused on design technologies related to comfort, in addition to weight reduction and

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safety technologies. Passenger comfort plays an important role in consumer purchasing decisions and is affected by various factors including vibration, noise, and air temperature control. The vehicle seat is in direct contact with the passenger and thus is key to comfort while in the vehicle. Vehicle seats can be classified into three parts: the cushion, backrest, and headrest, depending on the area of contact. The cushion supports a passenger's hips and consists of a seat cover, seat foam, suspension, and a seat frame [1–3]. Vehicle seats must possess various functionalities (*e.g.*, workability, safety, and conformability). With regard to workability and safety, the basic design methods are outlined by consumer law and safety standards. However, passenger comfort is difficult to reflect in the design, due to its subjective nature. Seat deformation varies greatly and depends on the passenger as well as the deformation type (*e.g.*, wrinkling, chapping, peeling, and loose seams). Seat covers are exposed to asymmetrical stresses when passengers sit on them, and repeated seating can cause wrinkles [4–8]. Seat covers are normally made of leather or fabrics; thus, viscoelastic properties are the significant factor in seat cover deformation. Because viscoelastic property means that deformation increases or load decreases as the time progress, it means that there will be degradation of materials verses initial material properties [9,10]. Cucos et al. showed that the viscoelastic properties of collagens, which are major elements of leathers, change in accordance with time and temperature [11]. That is, repeated seating of passengers causes seat cover deterioration and eventually becomes the first cause of loosening of the seat coverings. Loosened and saggy seat covers are then exposed to repeated deformations, such as chafing and friction, which eventually cause secondary damage in the materials [12–14]. Additionally, as wrinkles occur due to stress asymmetry, thermal deformation caused by changes in passenger position and temperature also influence wrinkles in the seat cover material. Thus, research and analytical methods are required to minimize seat cover wrinkles to optimize passenger seat comfort and wear [15–17].

This study was aimed at proposing a finite element modeling method for predicting wrinkles that occur due to repeated seating over a prolonged period of time. Viscoelasticity was taken into consideration to describe the deformation of the leather materials used in seat covers caused by time and repeated load applications. To evaluate the deformation of seat covers that had been exposed to repeated use over a certain period of time, cyclic loading-unloading tests were conducted on strip samples. One cycle was assumed to consist of the seating of a passenger, followed by driving, and then loading-creep-unloading were applied. The creep time was assumed to be 2 h; the cycle was repeated 60 times to obtain stress-deformation curves in each direction. To perform seating analysis, PAM-COMFORT, a finite element program specifically designed for seats, was used and permanent deformation of the seat was predicted. A material modeling method was introduced to consider the permanent deformation due to viscoelasticity and repeated loads; procedures for evaluation of the permanent deformation are described. Sample models were used for comparison with numerical test results; this approach was then applied to the seat module to predict the amount of wrinkling.

Table 1
Summary of material tests.

Materials	Test(test speed: 4 mm/min)	
Foam (foam pad/slab foam)	Uniaxial compression test	
	Uniaxial tension test	
	Stress relaxation test	
Seat cover	Uniaxial tension test	
	Cyclic loading-unloading test	with creep
		without creep

2. Materials

The cushion part of seats consists of foam pads, slab foams, and seat covers. Uniaxial tension tests and uniaxial compression tests for analysis of mechanical properties and stress relaxation tests for consideration of viscoelastic characteristics were performed. Material tests were conducted using test samples of the KS M ISO 3386-1 standard. For the slab foams, the test samples were constructed by laminating multiple layers, because the sizes of samples available were limited. In case of seat covers, analysis of viscoelastic properties by using repeated loads is necessary because degradation of properties occurs due to loading-unloading and this degradation causes reduction of covering. Fig. 1 shows the ideal responses of a seat cover that occur during the processes of a driver getting into (loading) and out of (unloading) a vehicle. Fig. 1(a) shows that the load and displacement over time can be divided into three parts: loading, constant loading, and unloading. In the loading stage, the passenger moves onto the seat, and the seat is exposed to deformation from aspects of the seat structure during this period. The constant loading stage appears while driving over a prolonged period of time; in this stage, the seat enters a viscoelastic state in which the load remains at a constant level. Here, creep characteristics appear in the seat cover. Finally, in the unloading stage, the stress recovers as

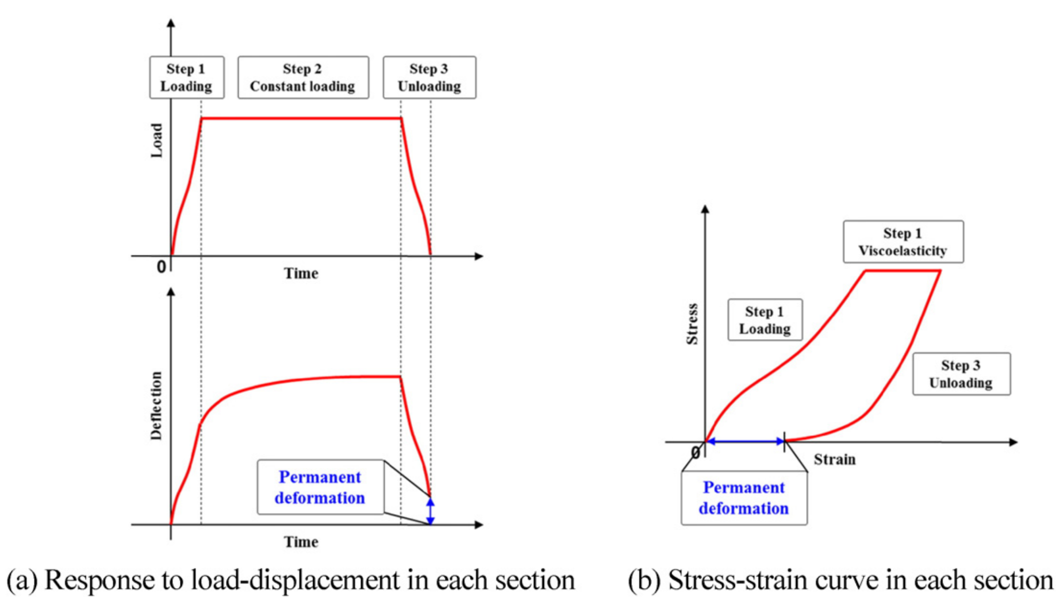

Fig. 1. Permanent deformation of a seat cover by viscoelasticity.