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FINITE ELEMENT ANALYSIS OF STRESS-STRAIN BETWEEN HUMAN HEAD AND HEADREST OF OFFICE CHAIR

WEIKANG Li[1], HANG Jiang[2], CHENGFENG Wang[1], ZHENGLI Li[2], TING Zhang[2], ONDER Tor[3], İSMAIL Derda Güler[3], LINGLING Hu[1*]

[1] *Department of Furniture Design and Engineering, Zhejiang A&F University, Hangzhou, China.*
[2] *Reasearch and Development Center, Xilinmen Furniture Co.,Ltd., Shaoxing, China.*
[3] *Department of Forest Industry Engineering, Kastamonu University, Kastamonu, Turkey.*
[4] *Department of Sustainable Bioproducts, Mississippi State University, Starkville, United States.*
*Corresponding author's e – mail: linglinghu@zafu.edu.cn

Abstract: This study employs finite element analysis to evaluate the influence of office chair headrest curvature and inclination angle on head-headrest interaction. A computational model, incorporating the Ogden Foam constitutive model for the soft material, was developed. Results indicate that while headrest curvature and inclination have minimal impact on overall deformation, the inclination angle significantly affects stress distribution. Specifically, von Mises stress on the head decreases with increased long-side curvature.

KEYWORDS: office chair, headrest, stress-strain, finite element analysis

1 Introduction

The sitter's comfort of the head and neck is closely related to the size, form, material, shape of the headrest on an office chair. The good support of a headrest can fully relax the head and neck. Therefore, the headrest has become an important part for the office chair. Franz et al. [1] analyzed the influence of headrest pressure distribution, foam hardness and head support position on human head and neck comfort. The study found that a half of the subjects showed that low pressure in the head area could lead to discomfort. They suggested to use stiff foam for headrest. Hong Pu [2] suggested that the height of the headrest should be set between 653-713mm, and the front and back position of the headrest should be set between 16-48mm. Sheng Qixuan et al. [3] analyzed the influence of the measurement parameters of headrest size and shape on human body's sense of support. They also pointed out that the range of ergonomic parameters of headrest is not clear and needs further study. However, limited research about the influence of headrest curvature and arc depth on its support performance was reported. This paper constructs the simulation model of head-headrest (Human head and office chair headrest combination), and the influence of the curvature and inclination angle of the headrest on the stress-strain between the head-headrest is predicted through the ANSYS Workbench in order to provide a reproducible analytical method for the design of office chair headrest.

2 Methodology

2.1 Head-headrest Model

Based on headrest information collected from the office chair market, the bending mode of the office chair headrest model (Figure 1) was established with three headrest size parameters (Table 1) in Soildworks[5].The headrest model and head model are established into Ansys Workbench, and the inclination angle of the head-headrest are 90°, 110°and 120°(Figure 2),

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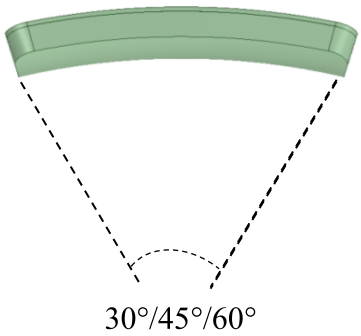
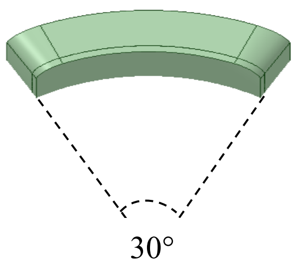
the fillet radius of 8 corners of headrest is 20mm. There is a certain distance between the head and the headrest, and the head is located in the middle of the headrest. A rigid material is placed at the bottom of the headrest to simulate the support of an office chair bracket. The number of meshes for a single combination is 32183.

Table 1：Simulation dimension parameters of office chair headrest

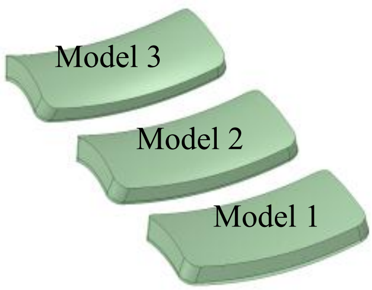
Length	Width	Long side curvature，Short side curvature	Inclination angle[2]	Thickness
300mm	160mm	Model 1：30°，30°	90°	30mm
			110°	
			120°	
		Model 2：45°，30°	90°	
			110°	
			120°	
		Model 3：60°，30°	90°	
			110°	
			120°	



(a) Bend the long side of the headrest



(b) Bend the short side of the headrest



(c)

Fig. 1 Model of office chair headrest

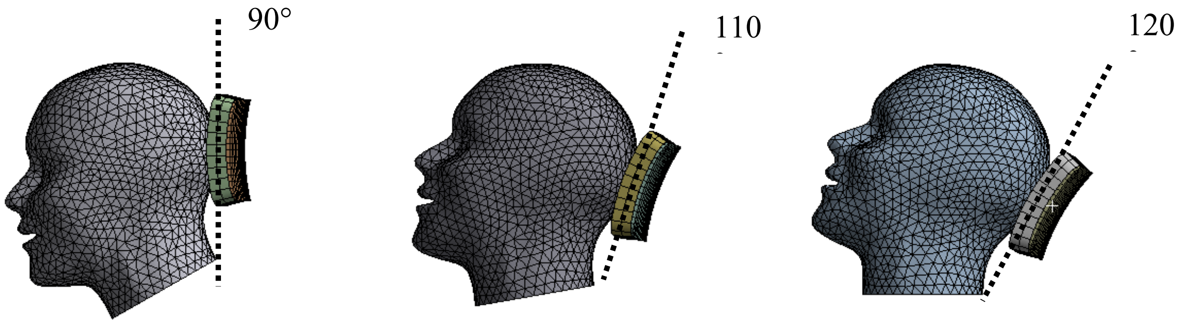


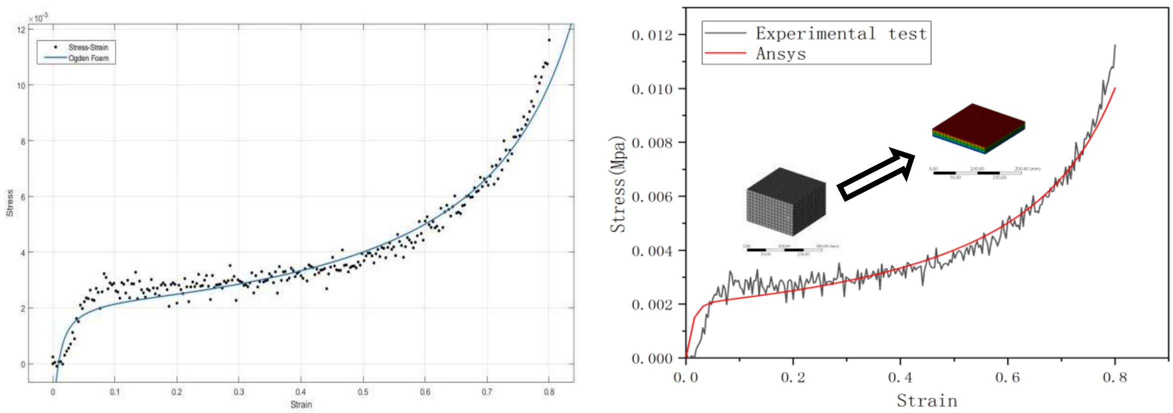
Fig. 2 The inclination angle of headrest

2.2 Material Models

The material of office chair headrest is polyurethane foam and covering. Due to the polyurethane foam in the headrest has a great influence on its stiffness, the influence of the covering is ignored in this study. Polyurethane foam falls under elastomers category, hyperelasticity is used to describe the material properties. The stress-strain relationships of polyurethane foam can be described using the Ogden Foam constitutive model [6 - 7] in Ansys Workbench. The Ogden foam material is described by the strain energy potential, W in the following form:

$$W = \sum_{i=1}^{N} \frac{u_i}{\alpha_i}\left(J^{\alpha_i/3}\left(\overline{\lambda_1}^{\alpha_i} + \overline{\lambda_2}^{\alpha_i} + \overline{\lambda_3}^{\alpha_i}\right) - 3\right) + \sum_{i=1}^{N} \frac{u_i}{\alpha_i \beta_i}\left(J^{-\alpha_i \beta_i} - 1\right) \tag{1}$$

where N is the order of fitting, u_i , α_i and β_i are the temperature dependent material parameters to be determined. J is the elastic volume ratio, λ_i is the principal stretches. Based on Ogden foam constitutive model[8], the uni-axial compression test data of polyurethane foam are fitted by fitting tool in MATLAB(Figure 3(a) and Table 2). According to the experimental test method, the values of fitting parameters are verified by Ansys Workbench(Figure 3(b)).



(a) (b)

Fig. 3 (a) Ogden foam constitutive model fitting test data(R^2=0.92);
(b) Comparison between ANSYS Workbench calculation results and test data

Table 2 Material properties for Ogden foam for headrest(N=2).

u_1 (Mpa)	α_1	β_1	u_2 (Mpa)	α_2	β_2
0.6915×10^{-5}	4.882	0	0.1998×10^{-2}	83.22	0

The head and headrest are assigned different material properties. The head in the model is defined as rigid material (The skull), the density of head is 1146kg/m3 .The Young moduli of head is separately set to 4460 MPa (Elastic 4460×106), while it Poisson's ratio is 0.21[9].

2.3 Loading and Boundary Conditions

Relative to the movement of the head, and the headrest is fixed in this study. In transient dynamics, the mass of the headrest can be set to 0 and the mass of the head is 13.69kg.It is supposed that the bottom surface of the headrest is restricted to move in all directions. The back of the rigid piece of material is fixed (Figure 4), then the Head Model hits to Headrest due to the gravity load (9.81 ms-2). Assuming that the contact time between the head and headrest is set to 0.05s (Fast collision) in Ansys Workbench [10]. The contact between the head and headrest is set as frictional, the frictional coefficient is 0.5[11].The contact between the rigid material and headrest is set as bonded.

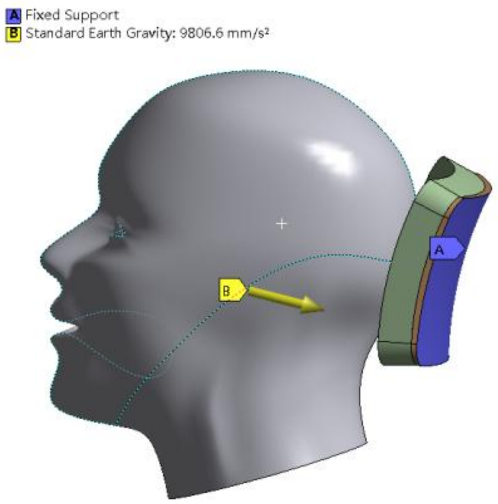


Fig. 4 Setting of boundary conditions
(The inclination angle of the headrest is 110°.)

3 Results and Discussions

Result comparison of the stress distribution and strain values of different headrests. It is observed from the analysis simulation, generally all cases shows the variation of stress distribution. Comparing Figures. 5, 6 and 7, the maximum von Mises stress occurs when the headrest inclination angle of 110°, 120°. As shown in Figures. 5(a), 6 (a) and 7(a), when the contact time between the headrest and the head is before 0.015 sec, the inclination angle of the headrest has less effected on the maximum von Mises stress. Table 3 describes the results of strain values of headrest from finite element simulation, it shows that the curvature and inclination angle of the headrest have less effected on the total deformation.

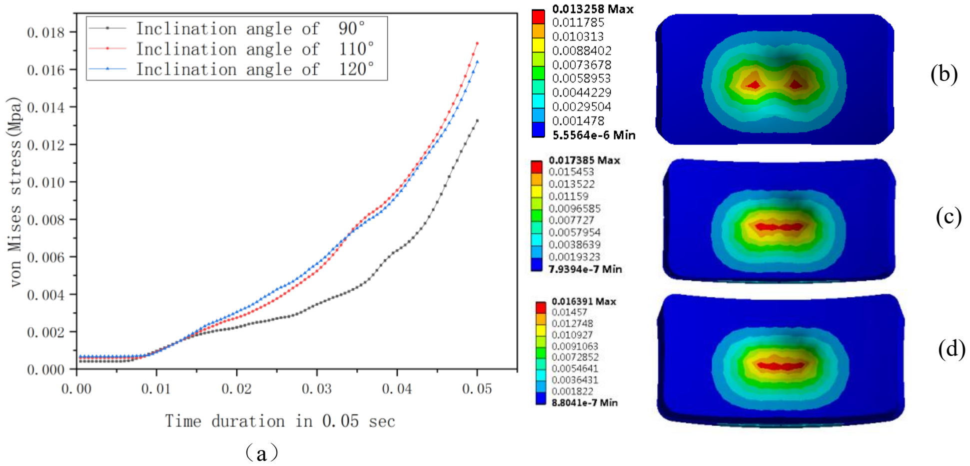


Fig. 5 (a) Variation of von Mises stress over time(Model 1：30°，30°);(b) von Mises stress = 0.01326MPa, inclination angle of 90°;(c) von Mises stress =0.01739MPa, inclination angle of 110°;(d) von Mises stress =0.01639MPa, inclination angle of 120°.

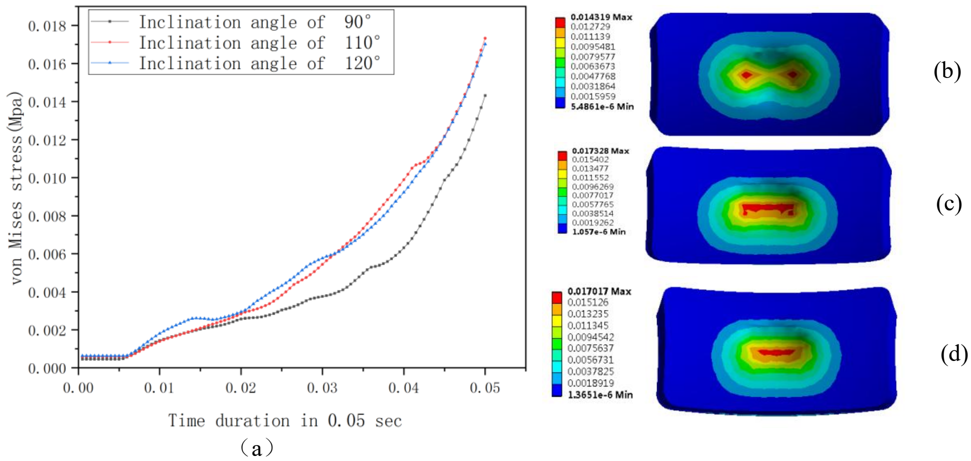


Fig. 6 (a) Variation of von Mises stress over time(Model 2：30°，30°);(b) von Mises stress =0.01431MPa, inclination angle of 90°;(c) von Mises stress =0.01733MPa, inclination angle of 110°;(d) von Mises stress =0.017017MPa, inclination angle of 120°.

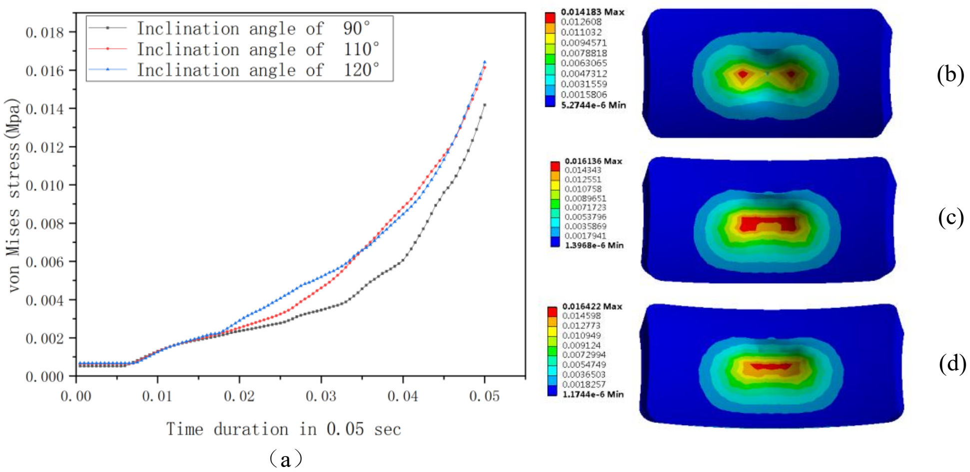


Fig. 7 (a) Variation of von Mises stress over time(Model 3：30°，30°);(b) von Mises stress =0.01418MPa, inclination angle of 90°;(c) von Mises stress =0.01614MPa, inclination angle of 110°;(d) von Mises stress =0.01642MPa, inclination angle of 120°.

Table 3 The Strain of the headrests.

Long side curvature, Short side curvature	Inclination angle	Strain
30°，30°	90°	0.544
30°，30°	110°	0.540
30°，30°	120°	0.518
45°，30°	90°	0.562
45°，30°	110°	0.578
45°，30°	120°	0.548
60°，30°	90°	0.553
60°，30°	110°	0.574
60°，30°	120°	0.550

Figure. 8 shows that as the inclination angle of the headrest increases, the supporting position of the headrest towards gradually moves towards the neck. The maximum stress of the head is greatly affected by the inclination angle of the headrest. In a certain range of angles, the inclination angle of the headrest can help the head and neck to obtain more supporting force. Figure. 8 also shows that the von Mises stress on the head decreases with the increase of headrest long side curvature.

CONCLUSION

This simplified simulation is designed to analyze the influence of headrest with curvature and inclination angle on head support, and provide a reproducible evaluation method for headrest design. Finite element method could evaluate the stress distribution and deformation of the headrest, and the stress distribution of the head. The simulation results show that the von Mises stress of the headrest is larger when the inclinations of the headrest are 110°and 120°.It also shows that the von Mises stress on the head decreases with the increase of the long side curvature of the headrest. The inclination angle and curvature of headrest have less effect on the total deformation of headrest.

Acknowledgments

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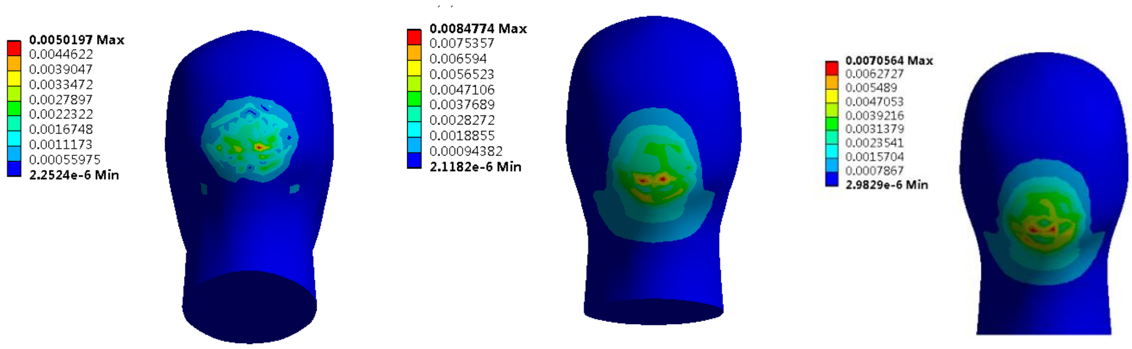
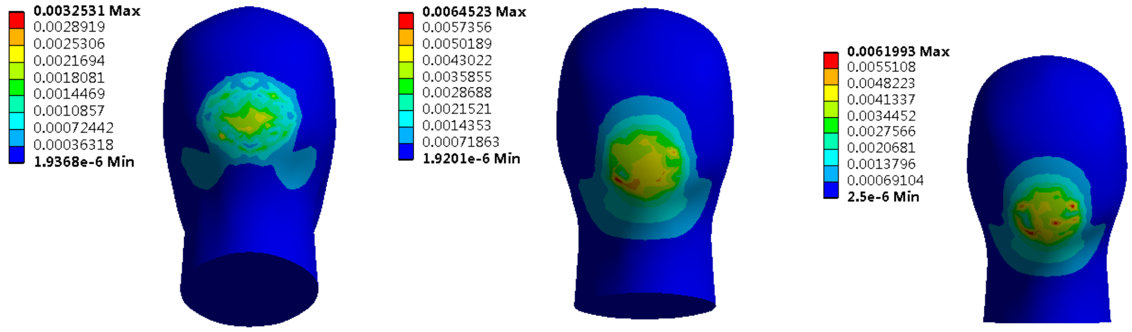


(a) von Mises stress =0.00502MPa
Inclination angle of 90°
(Model 1：30°，30°)

(b) von Mises stress =0.00848MPa
Inclination angle of 110°
(Model 1：30°，30°)

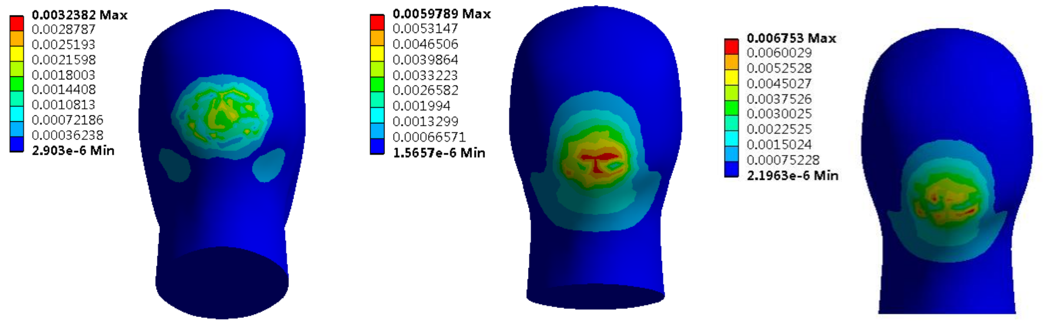
(c) von Mises stress =0.00706MPa
Inclination angle of 120°
(Model 1：30°，30°)



(d) von Mises stress =0.00325MPa
Inclination angle of 90°
(Model 2：45°，30°)

(e) von Mises stress =0.00645MPa
Inclination angle of 110°
(Model 2：45°，30°)

(f) von Mises stress =0.00620MPa
Inclination angle of 120°
(Model 2：45°，30°)



(g) von Mises stress =0.00324MPa
Inclination angle of 90°
(Model 2：60°，30°)

(h) von Mises stress =0.00598MPa
Inclination angle of 110°
(Model 2：60°，30°)

(i) von Mises stress =0.00675MPa
Inclination angle of 120°
(Model 2：60°，30°)

Fig. 8 The influence of different headrest on the stress distribution of the head

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