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Composite Car Seats Using Springs with Auxetic Material: A Numerical Simulation

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ABSTRACT

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Research conducted to date on structures having auxetic properties has focused on macroscopic scale and molecular analyses, and very few studies have examined auxetic models applicable to everyday objects. Auxetic pressure springs were used in this paper to produce a numerical model and to verify the quality of the furniture seats. Based on their surface stiffness and contact pressure distribution, system stiffness was determined. By performing a numerical study, the impact of seat modification with foam on the comfort of the seat when it was utilized was assessed. Furthermore, numerical modelling can effectively simulate complex, multilayer systems made out of materials with nonlinear characteristics, enabling rapid prototyping of these systems.

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Introduction

Several steps are involved in the design of a car seat. After designing the seat structure, the next step is selecting materials for the parts based on their ultimate strength, hardness limit, and Poisson's ratio. Here, continuous mechanics solutions are used to distribute normal contact stresses and create non-linear compression characteristics, which are the essence of this design stage. The unusual yet very useful property of negative Poisson's ratio material systems (auxetic materials) is that they become wider rather than thinner when stretched uniaxially. Among the characteristics of auxetic materials is their ability to reduce contact stress in contact with elastic media. Car seats can be designed using such structures. A soft seat provides a more uniform distribution of contact pressure than a hard seat as shown by Dhingra et al. [1]. It has been confirmed by Ebe and Griffin [2] that seating comfort and hardness can be measured by the contact pressure of ischiatic bones. The tissue damage caused by contact pressure and the duration of the action were correlated by Reswick and Rogers [3]. Based on the results of Kosiak [4; 5], microscopic variations in soft tissue occur as soon as the area of soft tissue is exposed to pressures that exceed 8 kPa for one hour. Previously, it has been highlighted that materials with nonlinear, progressive stiffness characteristics are used in seating and mattresses to achieve high user comfort. In the case of contact with the user's body, the seating was soft and exhibited big deflections at slight loads. As the load increased, the same seats became stiffer because deflections decreased disproportionately while contact stresses were compensated for [6-8]. Spring shapes and stiffness characteristics must be modified, but there is no comprehensive discussion in the literature on this matter. Capillary vessels can close under pressures between 2.7 and 4 kPa as reported in References [9; 10]. Because of this, seating and lying places with contact pressures of 4 to 8 kPa are widely analyzed [11-16]. Negative Poisson's coefficient structures are particularly intriguing. They have concave arms and greater deformation in the elastic range while having a much lower stiffness than materials with an identical relative density and a convex polygonal skeleton. Some researchers involved in the study of auxetic materials work on modelling and investigation [17-21]. Their research shows that by supporting a body on an auxetic seat, the vectors of internal forces are directed towards its centre, reducing friction and enhancement of seat comfort. As a result, auxetic materials should be suitable for both office and recreational seating due to their properties. The present study aimed to examine the quality of car seats made from auxetic pressure springs using numerical modelling. The stiffness of the system and distribution of pressure on the surface of the system were evaluated.

Numerical modeling

For numerical modelling, the auxetic springs presented in Figure 1 were used. Figure 2 shows the characteristics of the stiffness of auxetic springs under axial pressure. In this diagram, three compression zones can be distinguished. The first region affects the initial stiffness of the spring during which elastoplastic deformations occur. The second region forms a flat region where the displacements increase rapidly at almost constant load values. Finally, the third region begins along the end of the flat region, which indicates a uniform increase in stiffness due to the contact action of the spring arms. As shown in Figure 3, the seat of the chair was modelled as a symmetrical system of 16 elastic springs connected by strings and wrapped in polyurethane foams.

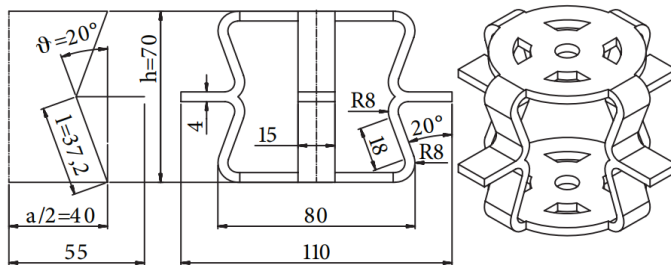


Figure 1. Design and 3D model of the auxetic spring.

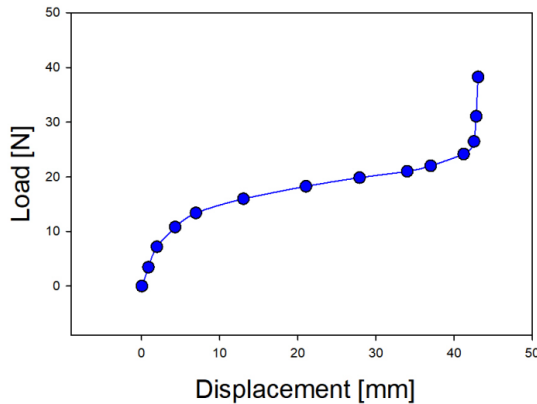


Figure 2. Characteristics of spring stiffness under axial compression.

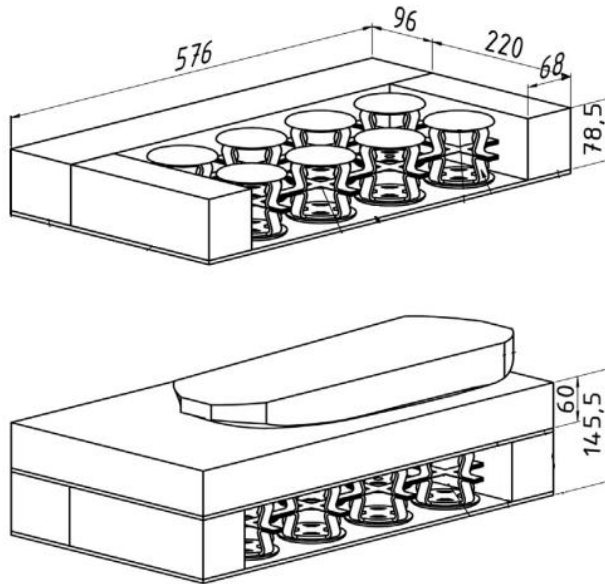


Figure 3. Seat with auxetic springs in a semi-symmetrical design.

Three numerical models were developed in this study. All models featured only half of the seat due to the symmetry of the system. A single spring with a cover was created in the first model (S). Foam filled the interior spaces between the frames, felts, and springs in the second model (SF). Unlike the first and second models, the third model (F) had no springs in the space between its frames.

Results and discussion

A comparison of S, SF, and F seats' stiffness characteristics can be seen in Figure 4, while deformations as calculated by numerical calculations can be found in Figure 5. Based on these results, it can be observed that the maximum deviation of the S seat reached 60.7 mm, while the maximum deviation of the SF seat was approximately 51.5 mm, and the maximum deviation of the F seat was approximately 53.3 mm. Both foam and springs show nonlinear progressive stiffness, yet these plots follow a linear pattern. Multi-layered seats, for instance, consist of multiple sections of materials with nonlinear properties, but their stiffness is independent of the stiffness of the components used in their fabrication. Furthermore, the stiffness of the seat component composite structure can be significantly affected by the boundary conditions of the seat components. It is possible for an elastic skeleton attached to the seat frame to withstand a greater load for a given amount of deflection than an equivalent set of individual elastic springs.

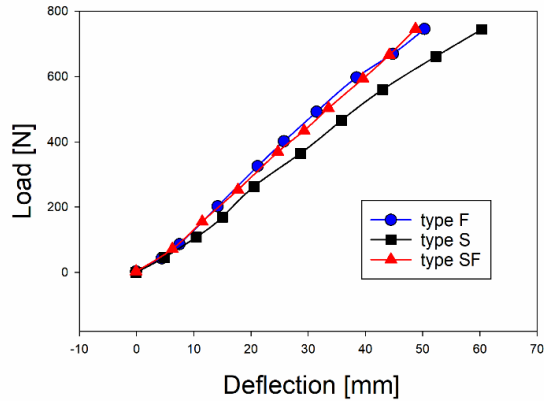


Figure 4. Changes in seat stiffness: type S - auxetic spring system, type SF - auxetic springs filled with foam, and type F - no spring.

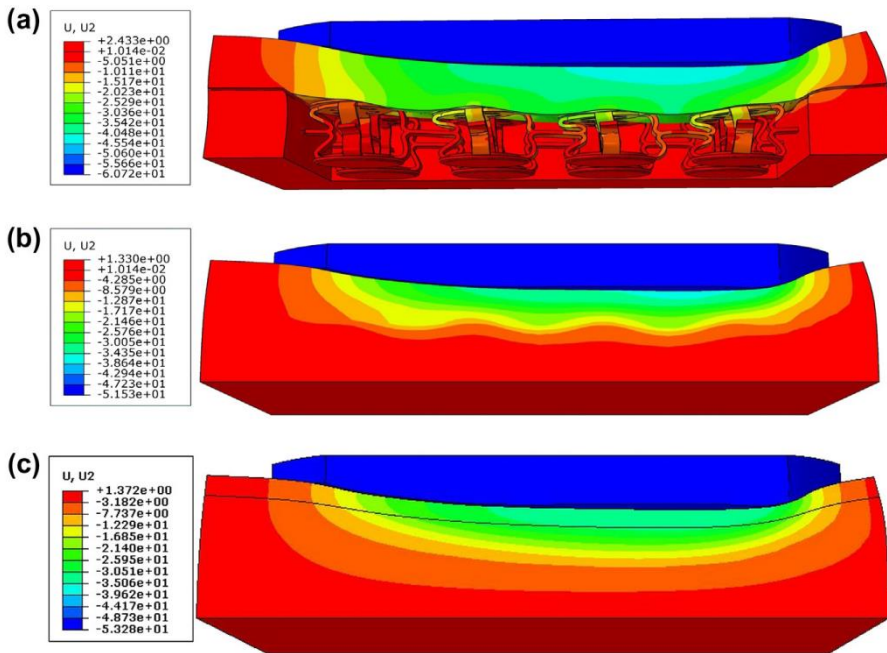


Figure 5. Deformation of seat: (a) S - a system of auxetic springs, (b) SF - a system of auxetic springs filled with foam, and (c) F - a system without springs.

As shown in Figure 6, the seat surfaces were subjected to different levels of contact pressure. As a result of this larger surface in the indentation pressure region, the pressure values were lower than those on the nominal surface. SF seats had a contact pressure of 12.81 kPa at the maximum deflection location, while S

seats had a pressure of 14.74 kPa; therefore there was a value difference of 29.5%. Additionally, the S seats had a higher pressure at point M than the S seats.

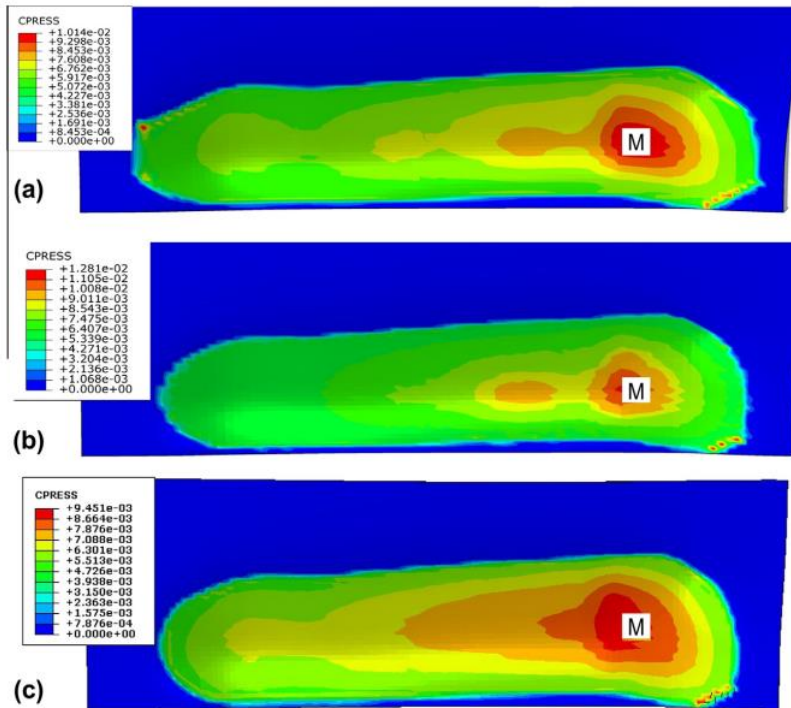


Figure 6. Contact pressure distribution on the seat surface: (a) S - system of auxetic springs, (b) SF - a system of auxetic springs filled with foam, and (c) system F - without springs.

Conclusion

Analyses of numerical data led to the formulation of several conclusions and remarks. It is possible to design comfortable upholstered furniture seats using auxetic springs, a new, original solution. It was possible to estimate whether modifying these seats by filling them with foam would improve their comfort of use based on a detailed numerical analysis of contact pressure. According to the results, the use of foam in the seat modification had no noticeable effect on the seats. Stiffness and comfort of utilisation were comparable between the examined seats. Furthermore, numerical modelling can be used to rapidly prototype multilayer systems consisting of materials with non-linear properties with complex geometry. Empirical verification of the numerical results was performed and interpretations of these results were established with regard to the scale of errors.

Disclosure statement and funding

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