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BODY PRESSURE DISTRIBUTION ANALYSIS OF LAYERED FOAM SYSTEMS

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Abstract:
This article presents the results of an experimental research based on the measurement of compression stresses of differently layered polyurethane foam structures with various foam sheet densities. For data acquisition the Tekscan's CONFORMAT body pressure distribution measuring system was used. The three-layered foam sheet system was loaded by a standard seat loading pad with four compression forces. Pressure distribution maps were recorded for all foam sheet variations and the contact surface and peak pressure values were determined. Based on the research results the comfort of the stratified cushion like structure was evaluated. According to the pressure distribution maps the homogenous foam layers with densities of 25kg/m^3 showed lower contact areas but a more uniform pressure distribution and lower peak pressure values. The heterogeneous stratification led to various contact surface areas and pressures, however, at 250N load force the 35-35-43kg/m^3 or 35-35-35kg/m^3 variations offer the highest contact surfaces and lowest peak pressures. At 500N load the 35-43-35kg/m^3 combination offer the best option, at 750N load the 35-25-25kg/m^3 and at 1000N the 43-25-25kg/m^3 variations have the optimal pressure distributions. Placing a transient foam layer between high and low density foam sheets did not indicate any significant attenuation.

Key words: *polyurethane foam; layered structures; comfort analysis; body pressure distribution; chair comfort.*

INTRODUCTION

Sedentary life-style of the human kind is getting more and more common leading to several musculoskeletal disorders. The increase of the seated occupations and sitting times raise the risk factors in the development of low back pain and other cardiovascular problems (Vink and Hallbeck 2012). Consequently, seating devices, i.e. chairs must provide more comfort to diminish the negative consequences of prolonged sitting. From ergonomics point of view, the high comfort is related to the well-being, safety feeling and healthy sensation of the chair users. However, the enumerated subjective evaluation criteria can be fulfilled mainly by objective design specifications. Consequently, the sitting comfort of a seating furniture is the combination of the embedded materials, construction and other design factors like dimensions, tilt angles, etc., which may either, add to or detract from the comfort of the finished product. Construction of upholstery, shape and hardness of the sitting surface are included also into features, which determine the sitting comfort (Kapica and Grbac 1998). The characteristics of upholstery are important for comfort and proper distribution of pressure nevertheless, the basic factor of contemporary comfort is the specific pressure to the body, not the softness of the seat. This pressure is smaller when the contact surface of the human body is larger (Ergié 2002, Grbac and Ivelić 2005). Other scientific articles focused also on revealing the relationship between sitting comfort and design specifications with the aim of reducing the discomfort of chair users. For example, Manfield *at al*. (2015) analyzed the discomfort in vehicle seats and concluded that foam composition can have significant implications on people undertaking journeys of long duration (more than 40 min. in the conditions tested). Comparing different foam types, they determined the difference in overall seat discomfort. Small changes to foam composition were shown to affect the overall discomfort in the seat. According to Vlaović *at al.* (2010) there are major differences among the materials of seat upholstery and their constructions. They conducted an experiment to determine the comfort index (support factor) of chairs obtained from elastic characteristics of materials in the seat of chair. In the result of examination of mechanical characteristic of chairs with polyurethane foams, a better comfort index has been noticed for chairs where in the subjective test evaluated as uncomfortable (Vlaović *at al.* 2010). In another study analyzing different types of seats, they concluded that the chair with molded PUR foam is significantly more comfortable than the chair with springs, but statistically it does not differ significantly from the chair with PUR foam cushion (Vlaović *at al.* 2016). According to Vink and Lips (2017) the form of the area contacting the body and the softness of this area influence the contact area between the body and the product. The pressure sensitivity of the skin and underlying tissue also plays an important role in the comfortability (Fig.1). Moreover, in seating design to create a comfortable seat it is important to define the foam characteristics of the seat pan or the flexibility of the material underlying the foam (Vink and Lips 2017).

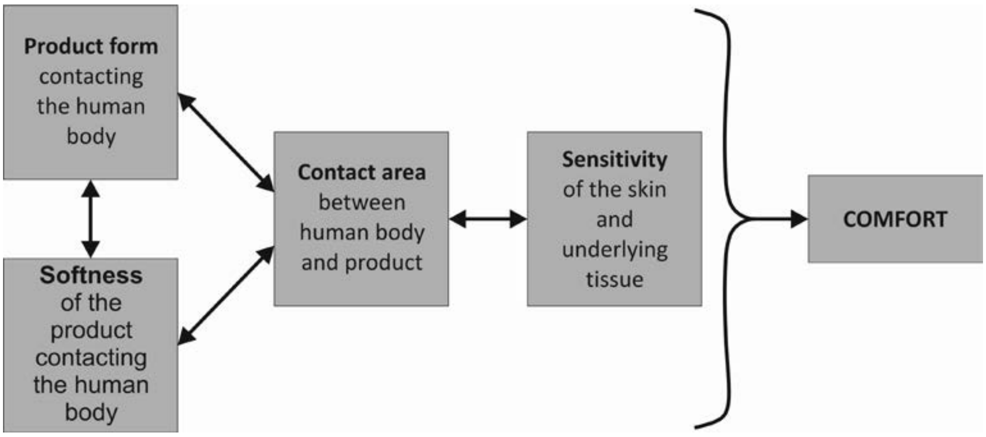


Fig. 1.
Modelling the characteristics which influence comfortability (source: Vink and Lips 2017).

According to US Patents there are some inventions relates to the field of cushions. Rose et al. (1994) disclosed a type of cushioning device in 1994. Their seat cushion was made of layers of polyurethane foam, each layers having a different density. Discrete orthogonal support system was invented by John D. Clark (2007). The stratified cushion assembly can be used to support the human body under various conditions and includes alternating strata of supportive material. Each stratum have a different compression modulus and strata of visco-elastic memory foam and open cell polyurethane foam are attached together (Clark 2007).

Other studies indicate that pressure measure seem to be a highly associated and objective method for the quantification of subjective comfort or discomfort (De Looze *et al.* 2003, Mergl 2006, Verver 2004). According Brienza *et al*. (2001) interface pressure mapping is an accepted method used by researches to evaluate pressure redistribution in seating. According to Zemp *et al.* (2015) pressure distribution measurements of the seat pan and the backrest are one of the most common objective methods to analyze or compare different sitting positions. Hochmann *et al.* (2002) evaluated four different seat pressure-mapping systems (FSA, Xsensor, Tekscan ClinSeat, Novel Pliance) concerning their accuracy, linearity and hysteresis. Pressure mats are very sensitive to differences in the surface area properties of the analyzed product, therefore it is very important that sensor mats to be calibrated for the corresponding surface (Zemp *et al.* 2016). According to Zemp *et al.* 2016, the pressure mat should be calibrated for every chair, as far as the pressure distribution measurements are influenced by different material properties and geometry of the padding material. Jackson *et al.* (2009) have shown that the best performing cushion had a layered structure made of approximately 25mm of Confor C47 foam with an overlay of approximately 13mm of Confor C45 (Confor is a medium density, open-celled polyurethane foam). They used a Tekscan type 5315 sensor mat for measuring the pressure over the seating and measured 5 different viscoelastic foam cushions that had not previously evaluated for gliders. The using method is suitable for comparing the comfort of different foams and combinations of foams. According to Horvath *et al*. (2016) the seat cushion can reduce up to 50% of the peak pressure of the sitting bones' (Ischial Tuberosity) zone. Not just the pressure mapping systems are used to define the comfort of seating furniture but the applied finite element model too, to simulate the contact interaction between human body and seat under different support conditions (Guo *et al.* 2016). Mohanty and Mahapatra (2014) analyzed the effect of cushion material properties and demonstrated that the use of right kind of foam for seat cushion and thickness can substantially reduce the stress level at ischial tuberosity. According to design engineers from Advanced Design & Analysis Division, IDOM and Centro Tecnologico Grupo Copo developed a virtual environment for foam seat testing. The study focused on the assessment of numerical simulations, primarily related to comfort using Abaqus Finite Element Analysis (FEA). The experimental results demonstrated that comfort parameters can be successfully simulated numerically and FEA is definitely a valuable tool for assessing seat designs for comfort.

OBJECTIVE

Based on the reviewed professional literature we could conclude that few research results exist related to the influence of chair foam cushions and sitting comfort. Therefore, the main objective of the present research was to evaluate the pressure distribution of layered polyurethane foam systems with foam layers having different densities and elasticities, using a body pressure distribution measuring system and a standard loading pad. A second objective of this research was to determine the optimal arrangement of a 3-layered system assuring the best comfort of the chair users.

MATERIAL, METHOD, EQUIPMENT

Polyurethanes are generally considered to be the most versatile among plastics, because of the variety of properties they possess. They are foam materials that can be manufactured at varying degrees of density and softness. Depending on the initial raw material they can be hard or soft, elastic or rigid. These foams have a wide variety of applications, for example modern homes and offices would be far less comfortable without polyurethanes. Flexible polyurethane foams are soft, yet provide good support, durable, and maintain their shape therefore are preferred as filling materials for seating cushions and mattresses and can be produced to the density required by the manufacturer. Their versatility allows designers to use the full scope of their imagination when creating new products.

For our research purposes open cell polyurethane foams with different densities produced by Eurofoam Hungary Ltd were used. The selected foam types frequently used by Hungarian upholstery furniture producers belong to the Eurofoam Classic family, class N and R. The properties of the selected foam types are presented in Table. 1:

Table 1

Characteristics of the PUR foams used in research

Type of PUR foam	Color	Density (kg/m^3)	Compression hardness, kPa (DIN 53577)	Tensile strength, kPa (DIN 53571)
Normal, N2538	Violet	25	3,8	110
Normal, N3530	Grey	35	3	90
Flexible, R4342	Green	43	4,2	100

From the selected foam types 600mmx600mm sheets with a thickness of 20mm were prepared and 3-layered structures arranged in every combination of the foam types, resulting in 27 experimental setups, totally. The layered structures were loaded with an anatomical seat loading pad according to standard EN 1728:2012.

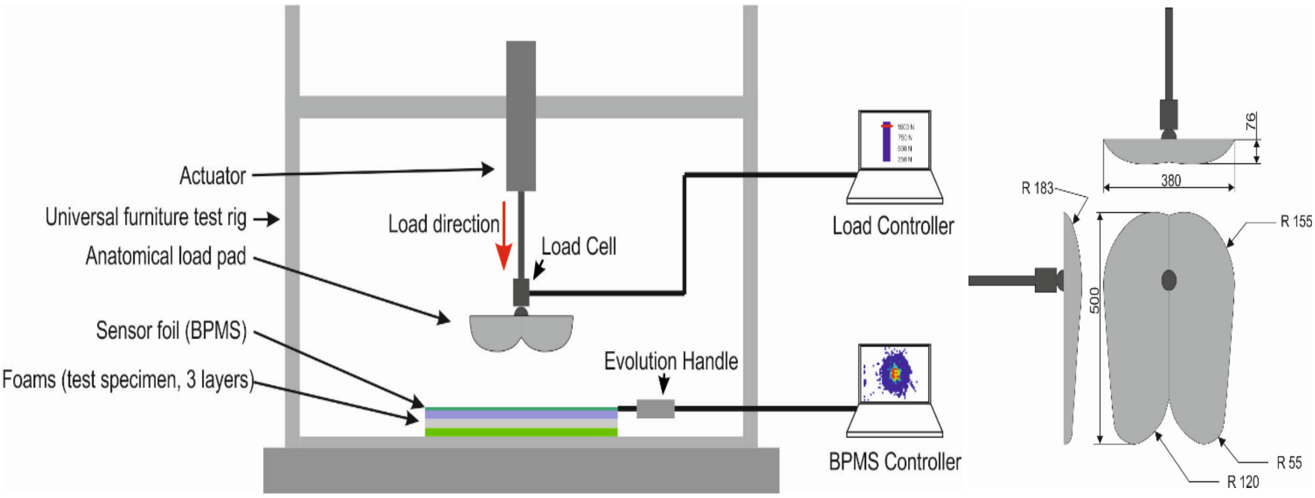


Fig. 1.
The schematic principle of measurements and the geometry of the loading pad.

The load intensity was set at four levels, 250N, 500N, 750N, and 1000N respectively, the maximum set load values were attained in 3 seconds. 108 measurements were made totally using the Tekscan's Body Pressure Measurement System (Conformat) with pressure sensitive foils size of 488×427mm containing

2016 pressure points with pressure range of 0-350mmHg, and accuracy of + / - 3.5mmHg. The computerized data recorder provides a real-time picture of the pressure distribution. The schematic principle of measurements is shown in Fig. 1. Before using the BPMS measuring system the pressure sensor foils were calibrated with the help of a vacuum pump. After calibration the pressure maps of layered foam structures loaded with four compression force values were collected and analyzed with the software delivered with the system (BPMS Research 7.20) in the form of image (.FSX or .jpg) or short (0-200 s long) video files. On the recorded pressure maps, the contact surface area and peak pressure values were determined.

Fig. 2. displays the experimental setup with pressing test rig, computer control and loading pad:

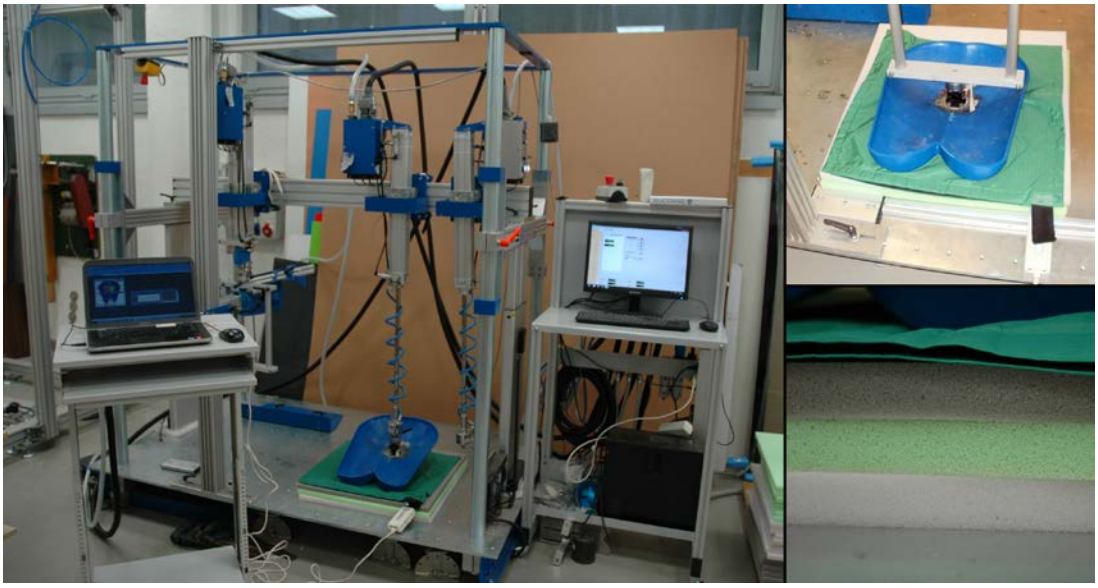


Fig. 2.
Laboratory test setup with the anatomical seat load pad and layered foam structure.

RESULTS AND DISCUSSION

The pressure distribution maps were recorded for all foam layers' variations and analyzed based on the contact area, pressure dispersion, pressure change intensity of different zones, etc.

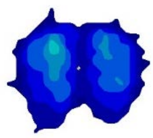
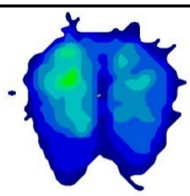
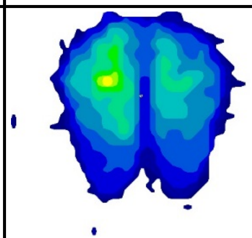
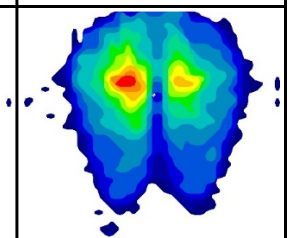
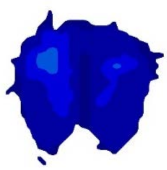
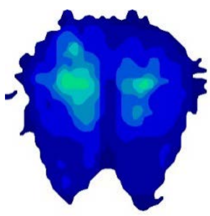
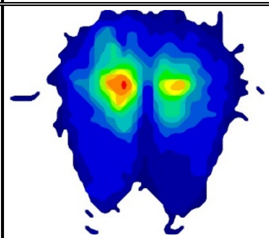
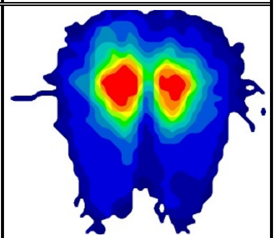
Pressing force, N	**250**	**500**	**750**	**1000N**
Foam density: **25 kg/m^3** (all 3 layers)				
Contact area, cm^2	399,48	669,93	946,58	1 095,22
Peak pressure, N/cm^2	1,12	1,50	1,98	2,59
Foam density: **43 kg/m^3** (all 3 layers)				
Contact area, cm^2	516,13	928,00	1 083,87	1 168,51
Peak pressure, N/cm^2	0,73	1,39	2,44	2,68

Fig. 3.
Pressure distribution maps of various pressure forces.

In Fig. 3. the effect of load intensity on homogenous layered foam structures is represented. The comfort normal foam type with lower density interact less with the load pad than the higher density comfort elastic foam however, the pressure distribution and pressure contours show more even dispersions mainly at higher loads. The lower density homogenous foam system induces lower shear stresses on the chair user assuring a higher comfort. The higher density foam compacts more therefore the deformation extends on a higher surface. A moderate asymmetry between right and left sides was observed.

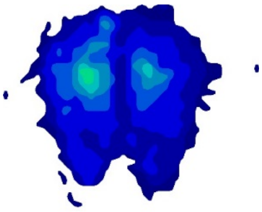
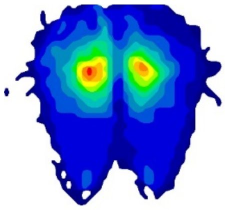
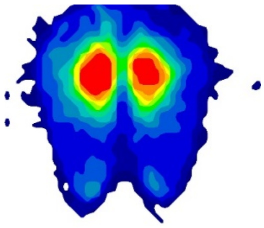
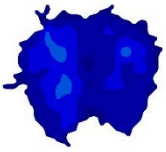
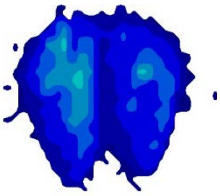
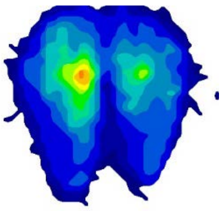
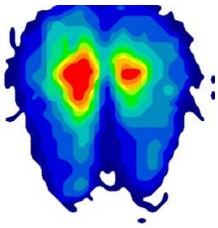
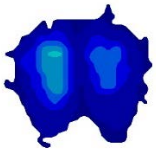
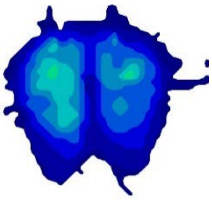
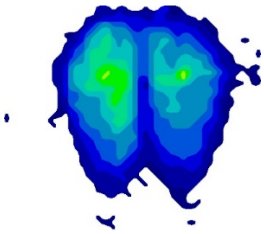
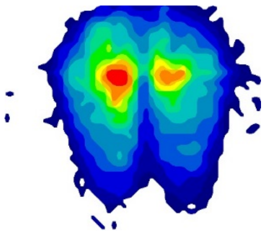
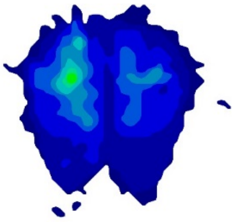
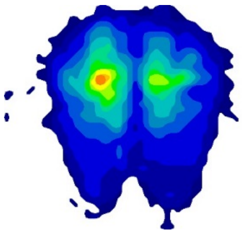
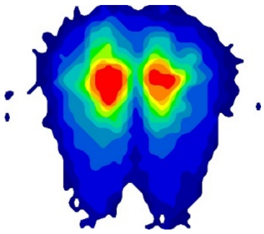
Pressing force, N	**250**	**500**	**750**	**1000N**
Layered structure: **25-43-43 kg/m^3**				
Contact area, cm^2	563,61	905,29	1 058,06	1 125,16
Peak pressure, N/cm^2	0,76	1,39	2,45	2,68
Layered structure: **25-25-43 kg/m^3**				
Contact area, cm^2	498,58	837,16	1 011,61	1 105,55
Peak pressure, N/cm^2	0,77	1,11	2,18	2,66
Layered structure: **43-25-25 kg/m^3**				
Contact area, cm^2	474,84	764,90	985,80	1 143,74
Peak pressure, N/cm^2	1,03	1,30	1,63	2,62
Layered structure: **43-43-25 kg/m^3**				
Contact area, cm^2	557,42	924,90	1 019,13	1 217,03
Peak pressure, N/cm^2	0,90	1,54	2,32	2,69

Fig. 4.
Pressure maps of different layered structures.

Fig. 5 presents the pressure distribution maps of heterogeneous structures when two layers of same low or high density foam sheets are combined with a third one of opposite density. In the case of high-high-

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low and low-low-high stratification the contact areas are very similar at any loading forces, but if the lower density foam layer is placed on the bottom the pressure is more uniformly distributed, the pressure gradient steepness is smaller. From seating comfort point of view, we found the best solution when a 43kg/m^3 density foam layer is placed on two 25kg/m^3 density layers.

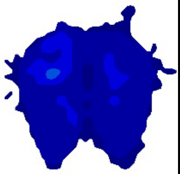
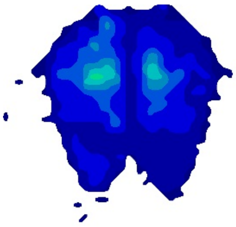
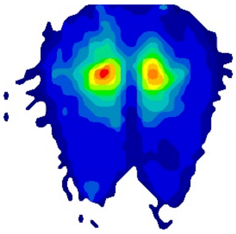
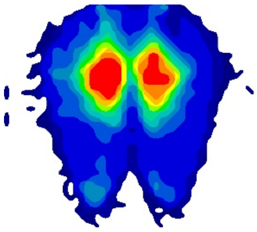
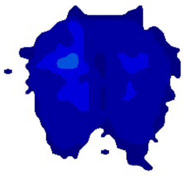
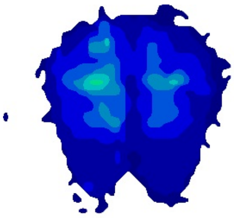
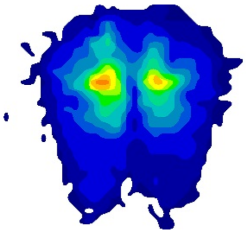
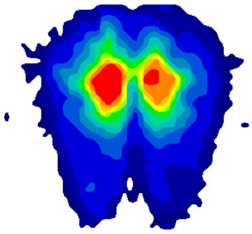
Pressing force, N	**250**	**500**	**750**	**1000N**
Layered structure: **25-35-43 kg/m^3**				
Contact area, cm^2	595,61	937,29	1 076,64	1 165,42
Peak pressure, N/cm^2	0,65	1,26	2,48	2,69
Layered structure: **43-35-25 kg/m^3**				
Contact area, cm^2	624,51	970,32	1 133,42	1 235,61
Peak pressure, N/cm^2	0,74	1,27	2,27	2,69

Fig. 5.
Pressure maps of layered structures with transient densities.

The influence of a transient layer with a density of 35kg/m^3 placed between the low and high density layers is shown in Fig. 5. The contact areas are maximum at all load values when the high density foam layer is placed on top, but the peak pressures are higher and pressure distribution is worse compared with the 43-25-25kg/m^3 structure. From pressure distribution perspective, the effect of transient layer is marginal. Loading the three layered foam structures with a load of 1000N lead to a peak pressure of 2,69N/cm^2 in almost all loading cases which demonstrates that the loading pad compressed the foam layers completely and was supported by the test rig's hard base. This means that a 60mm thick layered foam system using foams with 25,35,43kg/m^3 densities cannot attenuate completely the pressure exerted by a person of 100kg weight. The maximum peak pressure at 750N load was 2,61N/cm^2, and obtained by using a homogenous mid density foam structure. At 500N the highest value was 1,58N/cm^2 on a structure composed by foam layers having 35-35-25kg/m^3 density values. At the lowest load rate the peak pressure was 1,12N/cm^2 when a 25-25-25kg/m^3 configuration was used.

CONCLUSIONS

The comfort related pressure distribution on layered foam cushions was measured using a body pressure measuring system. A three-layered structure was prepared using upholstery foam types with three densities, and all possible variations. An anatomical loading pad imitating the human buttock loaded the layered structure using four pressure forces. Pressure distribution maps showing the compression load intensity, the pressure gradient, peak pressure values and contact areas were analyzed and evaluated from sitting comfort point of view. When homogenous foam structures were used the lowest density foams shown not just smaller contact areas indifferent of the selected loading forces, but a more even compression stress distribution. In the case of heterogeneous stratification, the lowest pressure values were determined for the high-low-low density configuration. Placing a transient foam layer between high and low density foam sheets did not indicate any significant attenuation. The lower peak pressure values do not always relate to a higher contact surface or even pressure distributions. Even though a hard anatomical loading pad was used for measurements a more or less accentuated antisymmetric pressure distribution between left and right zones were observed. Based on the recorded surface contact areas and pressure distribution maps an optimal layered cushion can be developed. For an average user a layered system composed by a 35-25-25kg/m^3 density foam sheets or 43-2543kg/m^3 sheets assure a more uniform and wide pressure distribution leading to a higher comfort sensation.

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