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Polyurethane Foam with a Negative Poisson's ratio for Diabetic Shoes

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Abstract

This study fabricated polyurethane foam after transforming the cell structure from a convex polyhedral shape to a concave shape. Polyurethane was synthesized and fabricated after changing the cellular structure of the foam using two methods. Scanning electron microscopy showed that the cellular structure was a more concave structure than in control foam. The Poisson's ratio of the experimental foam was negative. The average range of the Poisson's ratio was –3.4~0, versus 0.3~1.3 for the control foam.

Introduction

Circulatory problems are a major complication in diabetic patients. An injury or pressure on the foot can worsen conditions. Hence, it is very important that diabetic patients wear shock-resistant, elastic shoes. Consequently, the load distribution of the shoe is very important. Generally, polyurethane is used in the shoe industry. Polyurethane foams are also widely used in other applications, such as seat cushions, sound-absorbing material, and filters. These polyurethane foams have positive Poisson's ratios, ν, which is defined as the negative transverse strain divided by the axial strain. In isotropic materials, the Poisson's ratio should be between –1 and +0.5 [1].

Recently, foams with negative Poisson's ratios were discovered [2-4]. Foam materials based on several polymers were transformed into re-entrant foams, *i.e.*, they had inward-protruding cell ribs [5]. These foams were fabricated by transforming the cell structure from a convex polyhedral shape to a concave shape. A concave cell structure confers a negative Poisson's ratio on the cellular matrix [6]. Moreover, foams with a negative Poisson's ratio have improved mechanical properties in terms of the shear modulus, load bearing and load distribution, tear resistance, and ability to absorb impact without bottoming [1,7]. We prepared polyurethane foam with a negative Poisson's ratio for the insoles of the shoes of diabetic patients.

Materials and Methods

The polyether polyol was from Korea Polyol Co. (commercial name: KONIX FA-703). Distilled water was obtained in the laboratory and used as the blowing agent. Glycerine (Duksan Pure Chemical Co.) was used as a cross-linking agent. Methylene diphenyl isocyanate (MDI) was from Kumho Mitsui Chemicals (commercial name: M-200). Dibutyltin dilaurate (DBTDL, Aldrich Chemical Co.) was used as a catalyst. Silicone surfactant was from Osi Specialties (Commercial name: L-3002).

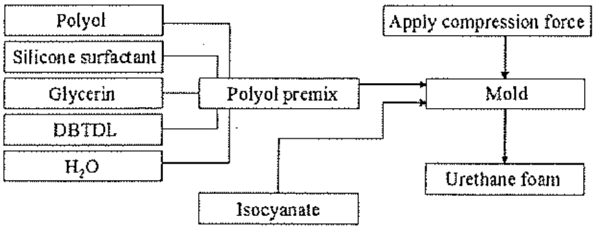

Figure 1. Two-component method

The polyurethane foam was fabricated using the 'Two-component method' (Figure 1). Polyether polyol, H_2O, glycerine, DBTDL, and silicone surfactant were put in a beaker and mixed with a stirrer for 2 min. Then, the reactants were mixed with MDI, and poured into an aluminum mold (70×70×65 mm) to produce volume-restricted foams. They were cured for 4 hours at room temperature.

Two methods were used to change the polyurethane foam structure. In the compression method, a compression force was applied immediately after the polyurethane foam reached the top of the mold (the force was applied after expansion had finished). In the restrict-volume method, the volume of the polyurethane foam was limited during foam formation (the volume was restricted before expansion).

The morphology of the prepared polyurethane foam was studied using scanning electron microscopy (SEM). A tensile test was performed on an MTS 858.20 Bionix testing machine. The transverse and longitudinal strains were measured simultaneously using an image processing method. The load was applied until the strain reached 7%.

Results and Discussion

The polyurethane expanded 13 times by volume during foam formation at room temperature. Figure 2 shows the structure of the prepared polyurethane foam. In the control (A), the cells were large and convex (expansion rate: 13 times), while the experimental foam using the restrict-volume method (B, expansion rate: 5 times) had areas of concave cells, which were also smaller (dark circle). Table 1 shows the Poisson's ratios of the polyurethane foams. As expected, the Poisson's ratio of the experimental specimens was negative. Figure 3 shows the coordinate system used to analyze the Poisson's ratio.

Table 2 shows the repulsive elasticity of the urethane foams. The repulsive elasticity was greater with the compression method than with the restrict-volume method. Figure 4 shows that the experimental specimen had better physical properties than the control. Pore size and the number and shape of the pores likely influenced the elasticity of the prepared polyurethane foam.

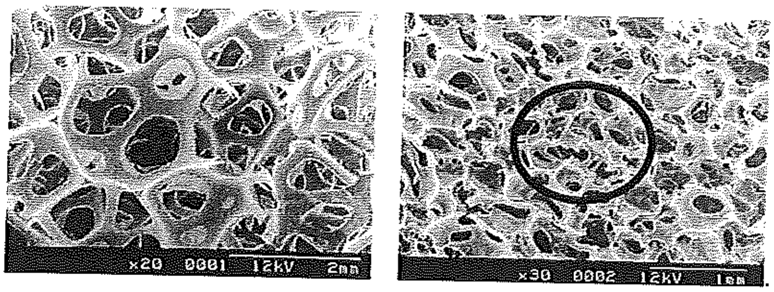

Figure 2. SEM photographs of the polyurethane foam: (A) free-rising foam (× 20), (B) foam subjected to a compression force during expansion (× 30)

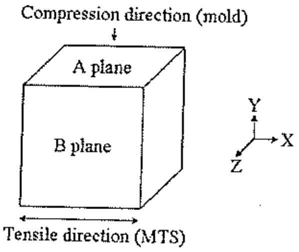

Figure 3. The coordinate system used for the polyurethane foam

Table 1. Poisson's ratio of the polyurethane foams

Strain (ε XZ, ε XY)	Control A plane (υ XZ)	Control B plane (υ XY)	Compression method A plane (υ XZ)	Compression method B plane (υ XY)	Restrict-volume method A plane (υ XZ)	Restrict-volume method B plane (υ XY)
0.2	0.84	0.6	-3.41	0	0	0
0.4	1.04	1.326	-2.13	0.744	0	-0.304
0.6	1.18	0.476	-1.067	0.496	-0.44	0.27
0.8	0.7	0.357	-0.48	0.37	-0.33	0
1.0		0.693		0.55	-0.264	0

Table 2. Repulsive elasticity of polyurethane foam

	Compression method	Restrict volume method	Control
Repulsive elasticity	52.3%	26.8%	21.5%

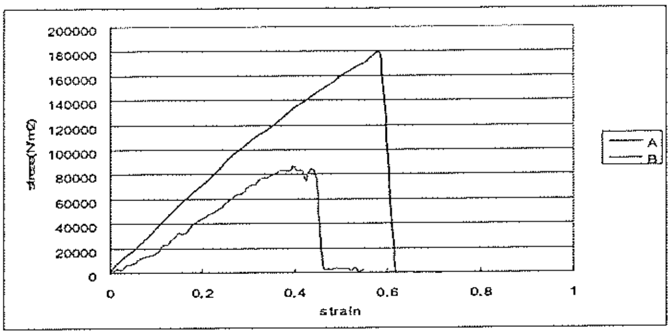

Figure 4. Typical result of a tensile test: compression method (A); control (B)

Conclusion

In this study, a simple compression force or restrict-volume method was applied during foam formation to change the cell structure. Less of the cellular structure was converted to the concave form than expected, as shown in Figure 2. However, both the restrict-volume and compression methods resulted in negative Poisson's ratios. The compression method was more efficient than the restrict-volume method in terms of the Poisson's ratio and repulsive elasticity, since the compression method applied a load after foam formation, while the restrict-volume method applied a load before foam formation. The negative Poisson's value improved the mechanical properties of the foam, such as its ability to cushion an applied impact without bottoming [1]. Its shock absorbance is currently under investigation.

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