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Compression testing of foamed plastics and rubbers for use as orthotic shoe insoles

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Abstract

Thirty-one materials have been tested in compression in order to generate the stress (force per unit of cross-sectional area) versus strain (deformation) behaviour, for the purpose of assessing the suitability of various foamed plastics and rubbers as shoe insole materials. It was found that the materials could be classified into three distinct categories (very stiff, moderately deformable and very deformable) according to the shape of the characteristic stress versus strain curve. The moderately deformable group has been selected as the most promising for clinical application.

Introduction

The conservative management of many common foot disorders involves the prescription of appropriate footwear, often requiring modification to the interior of the shoes. Rheumatoid arthritis may be considered a model with the well known problems of hallux valgus, hammer toes, flattening of the longitudinal arch, pronation of the hind foot, metatarsalgia, thinned skin and thinned subcutaneous tissues (Broadley, 1974). Possible orthotic solutions include metatarsal mounds, metatarsal bars, scaphoid pads, soft insoles and custom moulded foot orthoses incorporating pressure-distributing features (Hollingsworth, 1978; Adams, 1972; Hollander, 1974).

Leather, rubber and cork have been the traditional materials used in the fabrication of these various foot orthotic devices. In many centres newer materials, specifically foamed plastics and rubbers, are beginning to replace the traditional materials, but there is very little clinical or scientific information readily available about them. Choice of material tends to be based on personal experience, cost and/or availability. Plastazote is the most common thermoplastic material described in the medical literature. Other materials that are commonly used in North America, although not described as extensively, are: Aliplast, high density neoprene, and Spenco. Less commonly used materials are: Lynco, Celltite, Evazote and Poron, for which there is no data available in the literature. "Dr. Scholl's Cushion Insoles" and "Odor-Eater Insoles" are widely available to the public through drug stores and department stores, and again no data is available.

Our clinical experience suggests that one should consider the characteristics listed below when attempting to choose an insole material:

1. biocompatibility
2. ease of use
3. ease of fabrication
4. availability
5. durability
6. simulation of the mechanical properties of soft tissue
7. subjective comfort
8. cost
9. pressure distributing properties

We felt it would be possible to correlate measurable physical properties with the desirable clinical characteristics. To date, 31 materials have been identified by our group for this application, on the basis of information derived from the literature, shoe and foot clinics, technical material from companies producing the materials, and miscellaneous other sources.

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A series of tests (compression, shear, accelerated ageing, compression set and cyclic compressive loading) have been selected, which will provide relevant information about the physical properties.

This study was initiated for the purpose of determining the compressive properties for the 31 materials mentioned previously.

Methods and materials

The applicable test procedures for foamed rubbers and plastics, published by the American Society for Testing and Materials (ASTM) were reviewed. The subsequent procedure is a modified version of the Compression Deflection Test outlined in ASTM D1667–70.

Standard disc-shaped specimens (2·85 cm in diameter) were cut from each of the 31 materials, and the thickness of each specimen was measured with a dial micrometer. The specimen, in the form of either a single ply or multiple plies, was placed on the lower platen of a model 1125 Instron Universal Testing Centre and pre-conditioned by an initial compression to 23 kg. The upper platen of the Instron was positioned until it was in contact with the upper surface of the specimen. Figure 1 illustrates specimen placement in the Instron Testing Centre.

The specimen was compressed at a constant rate of 10 mm/min, 100 mm/min, or 500 mm/min to a maximum load of 23 kg. The maximum load of 23 kg is equivalent to a stress of 3·6 kg/cm² which is slightly greater than the maximum stress sustained by the foot during normal walking. (Godfrey *et al,* 1967). Since the results for the different plies at the various compression rates were comparable, only the results for the 10 mm/min compression rate on a single ply will be reported in this paper.

As a result of the unique structure of the product called "Pacer" it was necessary to slightly modify the test procedure solely for this material. The test specimen was a slab of the material, 2 cm larger than the size of the upper platen illustrated in Figure 1. The loading scheme outlined above was duplicated and the increased area of material tested was accounted for in the computation of the "Stress".

The load versus deformation recordings obtained as a result of the above procedure were plotted as "Stress versus Strain" curves. The magnitude of the "Stress" is computed by dividing the load at any location along the load versus deformation recording, by the cross-sectional area (6·36 cm²) of the specimen and it is expressed as kg/cm². The magnitude of the "Strain" is computed as the ratio of the deformation of the specimen (measured from the initial thickness of the specimen) divided by the initial thickness of the specimen. Strain is expressed as cm/cm or percent. The stress versus strain relationship is a common method employed in the field of materials science to illustrate the relevant characteristic of a material.

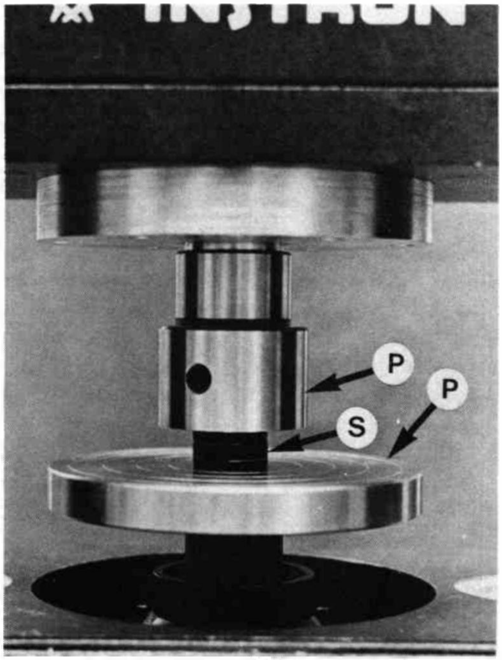

Fig. 1. The specimen of the material (S) is shown positioned between the platens (P) of the Instron Testing Centre.

Results

A typical stress versus strain curve is illustrated in Figure 2 using Lynco which is an open-cell, nylon-covered neoprene. The initial portion of the curve demonstrates a moderate increase in stress with a moderate increase in strain (moderate slope). The final portion of the curve illustrates a rapid increase in the stress with very little increase in the strain or deformation (steep slope). The intermediate portion of the curve is usually regarded as the transition region.

A similar review of the stress versus strain curves for the remaining materials revealed that

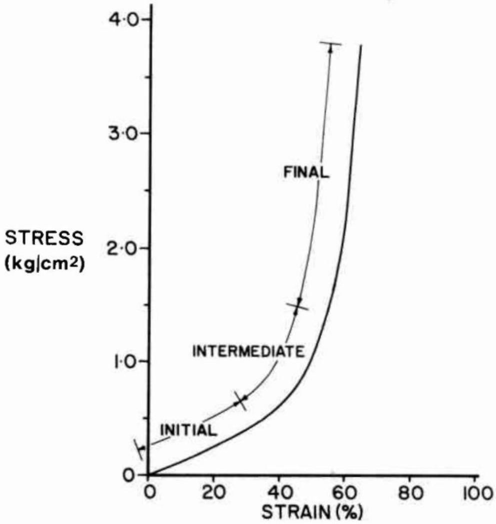

Fig. 2. A representative compression stress versus strain curve for the material "Lynco", illustrates the three portions of the curve.

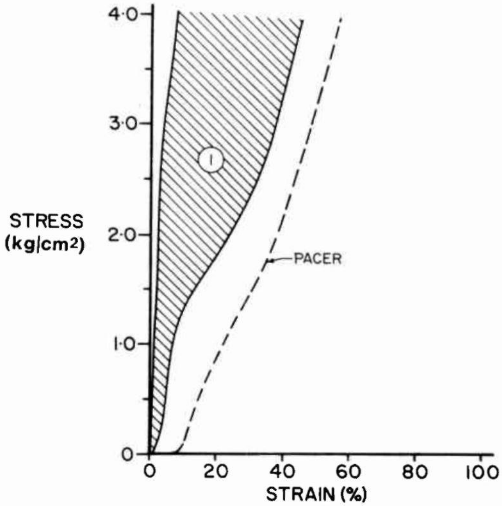

Fig. 3. The stress versus strain curve envelope for category 1 (very stiff), and the product "Pacer" (moderately deformable).

the materials could be classified into three distinct categories—very stiff, moderately deformable, and highly deformable, as illustrated in Figures 3, 4 and 5. The results for each category have been depicted as an envelope since the presentation of all the individual stress versus strain curves was considered confusing. Categorization of the materials is presented in Table 1.

The first classification (1) designated "very stiff" is illustrated in Figure 3 and is characterized by a continuous steep slope relative to the other materials. Examples of materials in this classification are Kemblo, Aliplast 10, and Pelite (1·6 mm). The product called Pacer illustrated in Figure 3 has been allocated to this category since it demonstrated an initial offset followed by a steep slope.

The second category (2) illustrated in Figure 4 and designated "moderately deformable" has two sub-classifications. The first subclassification (2A) demonstrates a high-moderate initial slope followed by a plateau region that gradually transforms into a steep slope in the final portion of the curve. The distinction between sub-classification 2A and 2B was determined by the arbitrary selection of a slope 2·9 kg/cm² for the initial portion of the curve. The materials

Table 1. Categorization of materials

Categories	Materials			
1 Very Stiff	High Density Neoprene Pacer	Aliplast—10 Kemblo	Pelite (1·6 mm thick)	
2A Moderately Deformable	Poron-20125 Aliplast-6A Poron-'Sport'	Plastazote-Low Density (3·2 mm, 6·35 mm thick) Neoprene-R 425N (6·35 mm thick) Neoprene-431 (3·2 mm, 6·35 mm thick)		
2B Moderately Deformable	Ensolite (3·2 mm, 6·35 mm thick) Evazote (1·6 mm, 12·7 mm thick) Neoprene-R 425N (3·2 mm thick) Poron-17125 Carpet—Wool (pile weight of 1·15 kg/m²) Carpet—Polypropylene (pile weight of ·74 kg/m²)	Aliplast-4E Ethafoam Celltite Pelite (12·7 mm thick)	Spenco Bonfoam Lynco	
3 Highly Deformable	"Dr. Scholl's Cushion Insole"	"Odor-Eater Insole	Polyurethane Foam	

illustrating this type of compressive behaviour (2A) are: Poron "Sport" and Aliplast 6A. The second sub-classification (2B) illustrated in Figure 4 has a low-moderate initial slope which gradually transforms into a steep slope in the final portion of the curve. Examples of this type of material are: Plastazote, Evazote, Pelite, Spenco, and Lynco.

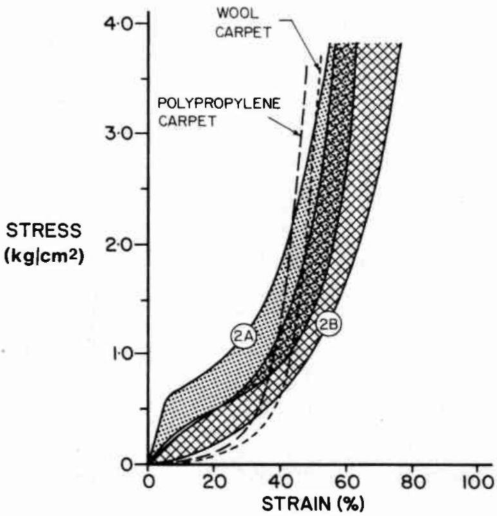

Fig. 4. The stress versus strain curve envelopes for category 2 (moderately deformable), divided into 2A an 2B. Also illustrated are the individual stress versus strain curves for polypropylene and wool carpets of different pile weights.

Two further materials assigned to category 2 are the wool and polypropylene carpets, since their characteristic stress versus strain curves overlap a substantial portion of this category. Nevertheless, the initial slope of the curve is very low, similar to category 3, but the amount of strain is considerably less.

The third category (3) illustrated in Figure 5 and designated "highly deformable", is characterized by a low initial slope which quickly transforms into a steep slope with a narrow transition region. Examples of the materials in this category are: Dr. Scholl's Cushion Insole and Odor-Eater Insole.

Materials which vary only in thickness usually fall within the same category (*e.g.*, Ensolite, Evazote, Neoprene 431). The slight difference in the initial portion of the curve between the 1·6 mm and the 3·2 mm thickness of Neoprene—R 425N accounts for the allocation to sub-groups 2B and 2A respectively. However, the

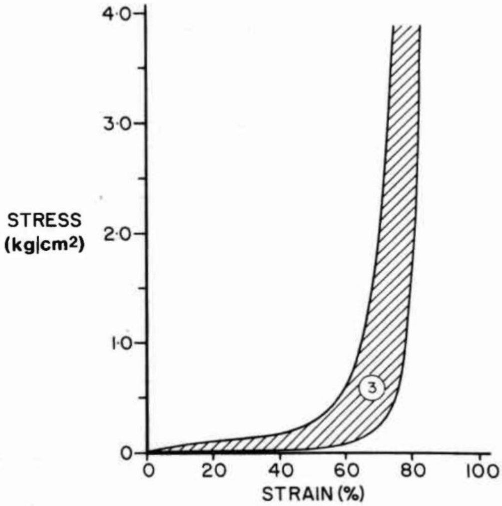

Fig. 5. The stress versus strain envelope for category 3 (highly deformable).

substantial difference for the characteristic stress versus strain curves for 1·6 mm and 12·7 mm thick Pelite indicate that the products vary in another factor such as density, polymer or structure.

Discussion

The visual assessment of the compression stress versus strain curves, provides a comparison of the compression characteristics for any group of materials. Compression of any foamed material by the bony prominences of the foot will result in an increase in the stress within the material which corresponds to the pressure or stress within the soft tissue covering the bony prominence. This situation could create excessive pressure and possible tissue breakdown about the bony prominences, unless the increased load is transferred to an adjacent area.

The ideal insole material would progressively deform throughout the full range of load to accommodate the shape of the bony prominence and to transfer a portion of the load to other less prominent regions of the foot.

The "highly deformable" group of materials (category 3) will deform rapidly under increased load until the material becomes almost completely compressed. Continued loading will result in very little further deformation of the material. The materials in this category reach this limit of deformation at a very low stress (about 0·5 kg/cm²). This rapid deformation of a material to its limit is commonly referred to as "bottoming-out". Since these materials will not transfer a significant portion of the stress to adjacent regions of the foot, they have been judged to possess poor characteristics for use as an orthotic shoe insole material.

The second category of materials which was described as "moderately deformable" demonstrates a reasonable degree of deformation with increased load, almost to the maximum anticipated stress. During loading, these materials will transfer the high pressure or stress associated with bony prominences to the adjacent tissue, thereby reducing the pressure on the bony prominences. Although the materials still exhibit a steep slope in the final portion of the compression stress versus strain curve, they have been judged to exhibit the most promising characteristics as an orthotic shoe insole material. At present, there is not a distinct preference between the materials with a gradual transition from the initial to the final portions of the curve, and the materials that exhibit a plateau in the transition region.

The "very stiff" materials in Category 1 deform very little, which prevents the redistribution of the stress on the bony prominences to the adjacent tissue. Consequently, materials in this category used by themselves are probably less useful as an orthotic shoe insole material.

An assessment of the suitability of a particular material for use as an orthotic shoe insert based exclusively on the compression stress versus strain curve associated with a material is not justified, since there are many other factors which must be considered. Further tests are in progress to investigate other properties of foamed rubbers and plastics to assess the applicability of these materials for clinical use.

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