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Caracterización Mecánica de Materiales Para Manufactura de Plantillas Semipersonalizadas Para Calzado Deportivo / *Mechanical Characterization of Materials For Manufacture Semi-Customized Insoles For Sports Shoes*

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Resumen:
Existen ciertos factores a tomar en cuenta en el diseño de componentes de calzado, entre ellos el material utilizado para la plantilla, que es la encargada del contacto entre el calzado y el pie. Conocer las propiedades mecánicas de estos materiales es de suma importancia para la selección de los materiales para mejorar el diseño del calzado deportivo. El objetivo de este estudio fue determinar las propiedades mecánicas de distintos materiales de tres de los principales proveedores en la ciudad de León, para seleccionar un material acorde al uso que se le dará al calzado. Se tomaron muestras y se realizaron pruebas de tracción para obtener sus propiedades mediante el dispositivo de ensayo universal Instron. El EVA de 3.2 mm de espesor del proveedor 3 fue el que mejores propiedades elásticas tiene con un módulo de Young de 2.458 MPa y un coeficiente de Poisson de 0.36. En lo que respecta al látex proveniente del proveedor 2, el látex antibacterial es el que presenta las mejores propiedades elásticas con un módulo de Young de 0.580 MPa y un coeficiente de Poisson de 0.14. Debido a lo anterior se recomienda utilizar EVA como material principal para la manufactura de plantillas debido a que este cuenta con un módulo de elasticidad mayor.

Palabras clave: Materiales, plantilla, calzado deportivo, manufactura de plantillas, ortesis plantares, pruebas de tracción.

Abstract:
There are certain factors to analyze in the design of footwear components, including the material used for the insole, which is responsible for the contact between the footwear and the foot. Knowing the mechanical properties of these materials is very important for the selection of materials to improve the design of sports shoes. The aim of this study was to determine the mechanical properties of different materials of the three main suppliers in the city of León, to select a material according to the use that will be given to the footwear. Samples were taken and tensile tests were performed to obtain their properties in the Instron universal test device. The EVA of 3.2mm thickness of supplier 3 was the one with the best elastic properties with a Young's modulus of 2,458 MPa and a Poisson's ratio of 0.36. As regards the latex from supplier 2, the antibacterial latex is the one with the best elastic properties with a Young's modulus of 0.580 MPa and a Poisson's ratio of 0.14. It is recommended to use EVA as the main material for manufacturing insoles because it has a greater modulus of elasticity.

Keywords: Material, insole, sports shoes, insoles manufacture, plantar orthoses, tensile tests.

1. Introduction

Nowadays the footwear industry is one of the main transformation activities in the city of León, Gto., It represents 22% of what is produced in the city and generates 20% of employment (García Hernández, 2009), therefore, the development of supply has been increasing as a result of this industry. The fit between the foot and the footwear has to make the user feels comfort, and the functional properties of the footwear must be favorable for the activity for which they were developed (Goonetilleke, 2012). One of the main components to guarantee a compliant and good quality product in the footwear sector is the insole and midsole, it is usually composed of celtec and latex; the first is a material that confers stiffness and allows the natural movements of the foot, the second is a hyperelastic material that favors comfort.

Footwear that has been manufactured with a thick and soft midsole has been associated with increased dynamic instability and reduced postural balance (Law et al., 2019) (Sekizawa, Sandrey, Ingersoll, & Cordova, 2001). A thin midsole improves both stability and balance (Menant, Steele, Menz, Munro, & Lord, 2008)(Perry, Radtke, & Goodwin, 2007)(Apps, Sterzing, O'Brien, Ding, & Lake, 2017), however, it can decrease the relative comfort of the user. Due to the above, the correct thickness of the midsole and insole guarantees the production of a functional footwear with adequate comfort, although it is necessary to consider that a thick material in the midsole deforms more than a thin one, and due to this impact forces are more attenuated in the thick midsole giving the midsole a better shock absorption (Barnes & Smith, 1994).

But with the complex structure of the foot, the foot-footwear relationship requires different adjustments in different parts, a poor fit between the foot and footwear can trigger stress and according to the activity performed generate pain and even injuries. There are different characteristics in the materials that help to understand how the material will behave according to the efforts to which it is exposed, in this study the following properties of the materials are analyzed: density, toughness, maximum stress supported, tension during breaking, Young's modulus and Poisson's ratio.

2. Method Description

For the development of this project, the research objectives were first created in order to know what is the material that provides the best elastic properties to be used in the development of insoles. The first is to identify the main materials that are used for the production of insoles, then characterize them and analyze their mechanical properties, a decision can be made answering to what is the appropriate material to use according to the activity for which it is developed the product.

2.1. Insole Description

The insoles are the part of the footwear that is placed to have contact with the foot, the insoles can have different purposes according to what the user requires, such as: odor control, plantar arch support, cushioning, pain reduction, control of humidity, among others. To confer any of these characteristics that the user wants, it is necessary to analyze several factors for the design of the insole, such as the structure or the material available for manufacturing.

2.2. Suppliers and insole material in León

The materials of which the products are composed give different characteristics and properties to the products used in everyday life. Materials engineering is mainly interested in the use of fundamental and applied knowledge about materials, so that they can be converted into the products that society needs or desires (Smith & Hashemi, 2006).

León is the main producer of footwear nationwide producing more than 60% of footwear produced in the country (Rocha Aceves & Iglesias Lesaga, 2006), therefore, there is a supply of components used for the manufacture of footwear, among the main suppliers are: leather, textiles, polymeric materials, ornaments, adhesives, midsole components.

Polymeric materials include high density polymers for the manufacture of outsoles such as TR (Thermoplastic Rubber), EVA (Ethylene Vinyl Acetate) and PVC (Polyvinylchloride), and low density such as latex, EVA and foam polymers being these the most used for prefabrication of midsoles and insoles. Table 1 shows some characteristics of the materials mostly used for the manufacture of sports insoles.

Material	Description	Advantages	Disadvantages
EVA	Close cell material.	Shock absorption (soft), durable, firm, heat moldable.	Limited damping. Compressibility
Polyurethane	Open cell material.	High shock absorption, compression resistant.	Durability as top cover, not heat moldable.
Polyethylene	Close cell material.	Durable, resistant, malleable, low weight, flexible, heat moldable.	Easy to compress, moderate shock absorption.
Latex	Close cell material.	Soft cushioning system that helps absorb impacts and reduce friction.	Low durability

Table 1. Materials mostly used for the design of sports insoles.

For the location of the suppliers of these materials, went to ANPIC (Asociación Nacional de Proveedores de la Industria de Calzado) the most important expositor's fair in the country for the leather-footwear sector organized by CICEG (Cámara de la Industria del Calzado del Estado de Guanajuato) attended by 350 exhibiting companies and more than 11,000 buyers and visitors. Three suppliers of these materials were found, for commercial reasons their names are not shown, ¡Error! No se encuentra el origen de la referencia. shows the suppliers and the materials that are mostly marketed for the manufacture of insoles.

Supplier	Material	Thickness
S1	EVA	2.5 mm
	EVA	3.0 mm
S2	Generic latex	5.5 mm

	Antibacterial latex	3.2 mm
	Activated carbon latex	3.0 mm
S3	EVA	3.2 mm

Table 2. Materials mostly marketed by suppliers in León.

2.3. Acquisition of technical data sheets

Suppliers were asked for the technical data sheets of the materials to corroborate and compare their characteristics, and see how the designer can take advantage of these for the design, in the parameters found in the technical sheets it was observed that they do not present any mechanical property, instead, they concentrate on chemical properties according to the formulation of the material, therefore, there is a need to continue to the stage of testing the material to determine its mechanical properties.

2.4. Material density

Density is a scalar magnitude that measures the amount of mass in a given volume of substance. To determine the density of the material, ¡Error! No se encuentra el origen de la referencia. is used, which states that the density is given by the amount of mass in a given volume of substance.

$$p = m/V \quad (1)$$

Where:
p=Density
m=Mass
V=Volume

To determine the mass of the materials, blocks of material 5cm wide x 5cm long were created and they were weighed on a precision scale. To determine the volume of the materials, the 5cm wide x 5cm long blocks were taken and multiplied by the thickness of each material, creating a rectangular prism, to which ¡Error! No se encuentra el origen de la referencia. is applied to determine the volume.

$$V = wxlxt \quad (2)$$

Where:
V= Volume
l= long
w= wide
t= thickness

Subsequently, the density values were calculated for all the materials, which are shown in Table 3. According to the values found, the material with the highest density is the antibacterial latex and the material with the lowest density is the 2.5 mm thick EVA.

Supplier	Material	Volume(cm³)	Mass (g)	Density (g/cm³)
S1	EVA 2.5mm	6.25	0.518	0.083

	EVA 3.0mm	7.5	0.680	0.091
S2	Generic latex	11.25	2.131	0.189
	Antibacterial latex	8	3.411	0.426
	Activated carbon latex	8	2.629	0.329
S3	EVA 3.2mm	8	0.838	0.105

Table 3. Density calculation of each material.

2.5. Tensile test

The tensile test was performed on the universal Instron testing machine which measures the load supported by the material before breaking, the Instron device is shown in Figure 1a. The tests were performed under ASTM 638 (Standard Test Method for Tensile Properties of Plastics).

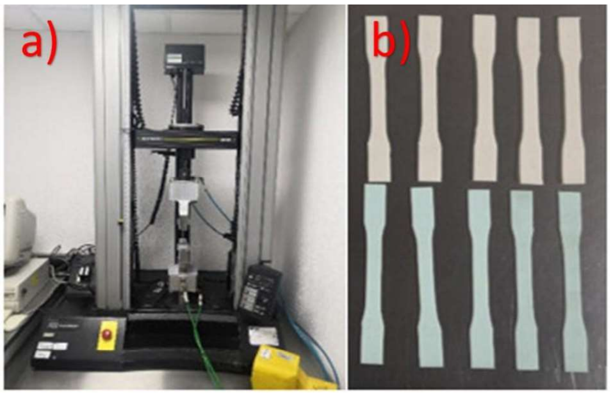

Figure 1. a) Instron universal testing machine, b) Dumbbell-shape test specimens due ASTM 638.

Five dumbbell-shape test specimens were created per material of 175mm long x 12mm wide to be subsequently tested in the Instron device, shown in Figure 1b the test specimens cut according to ASTM 638 to be tested in the tensile test. The main properties of the test are the following:

- Young's Modulus (MPa)
- Maximum Tension (MPa)
- Deformation before breakage (%)
- Tenacity (MPa)

The main results of the tensile test are shown in Table 4, it is observed that there is a marked difference between the Young's modulus of the EVA and the latex regardless of their formulations, the EVA of 3.2 mm thickness is the one with the greater Young’s modulus meaning that it is capable of support greater effort before losing its elastic properties, however, it is the material with the least deformation before breakage, despite this it is the material with the greatest tenacity with 0.932 MPa . The stress-strain diagrams for the latex in Figure 2 and for the EVA in Figure 3¡Error! No se encuentra el origen de la referencia. are shown.

Supplier	Material	Young's modulus (MPa)	Tension Max (MPa)	Def breakage (%)	Tenacity (MPa)	Tension during breakage (MPa)
S1	EVA 2.5mm	1.995	0.833	139.25	0.750	0.833
	EVA 3.0mm	1.650	0.916	231.55	1.383	0.916
S2	Generic latex	0.540	0.247	227.88	0.399	0.224
	Antibacterial latex	0.580	0.312	266.73	0.574	0.310
	Activated carbon latex	0.561	0.239	218.90	0.366	0.233
S3	EVA 3.2mm	2.458	1.060	138.45	0.932	1.060

Table 4. Main results of the tensile test.

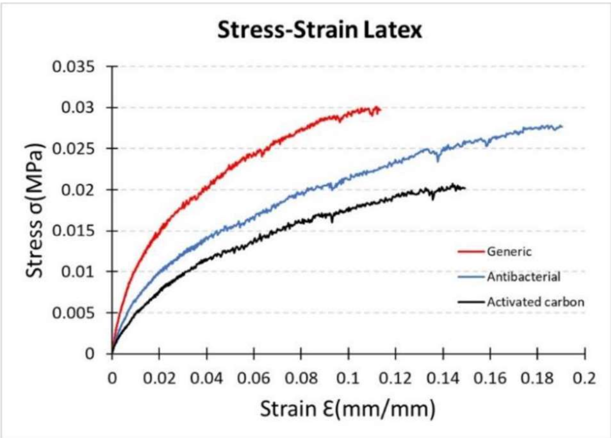

Figure 2. Latex stress-strain curves.

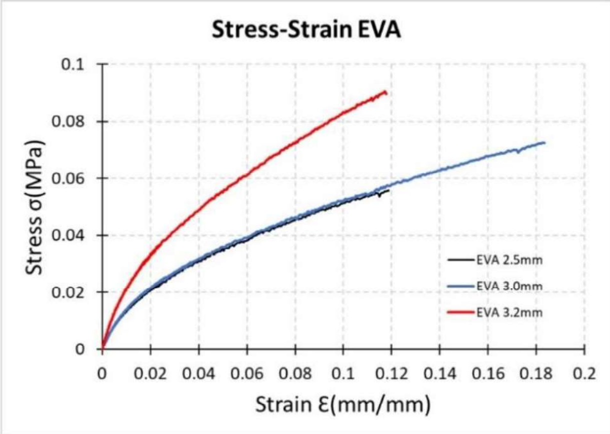

Figure 3. EVA stress-strain curves.

2.6. Poisson's ratio

To determine the Poisson's ratio, it was performed under ASTM E132-17 (Standard Test Method for Poisson's Ratio at Room Temperature). ¡Error! No se encuentra el origen de la referencia. is used, which indicates the relationship between the longitudinal deformation in the perpendicular direction of the applied force and the transversal deformation, being able to take as reference any of the two transverse axes. ¡Error! No se encuentra el origen de la referencia. shows the values found for each of the materials.

$$v = -\frac{\varepsilon y}{\varepsilon x} = -\frac{\varepsilon z}{\varepsilon x} \qquad (3)$$

Where:
v= Poisson's ratio.
εx= Longitudinal deformation x
εy= Transversal deformation y
εz= Transversal deformation z

Supplier	Material	Longitudinal deformation εx*(mm/mm)*	Transversal deformation εy*(mm/mm)*	Poisson v
S1	EVA 2.5mm	0.98	-0.30	0.31
	EVA 3.0mm	1.48	-0.42	0.29
S2	Generic latex	1.55	-0.16	0.11
	Antibacterial latex	1.78	-0.25	0.14
	Activated carbon latex	1.49	-0.28	0.19
S3	EVA 3.2mm	0.98	-0.35	0.36

Table 5. Calculation of the Poisson's ratio for materials.

3. Results and Discussions

Difference was found between the mechanical properties of EVA and latex, EVA is able to support greater effort before losing its elastic properties, it is recommended to analyze the properties of the material for the use that will be given to the product. According the studies EVA from supplier 3 and 3.2mm thickness is the one with the best elastic properties with a Young's modulus of 2,458 MPA and a Poisson's ratio of 0.36 and a tenacity of 0.932 MPa. On the other hand, the latex from supplier 2 has similar characteristics, however, the antibacterial latex is the one with the best elastic properties with a Young's modulus of 0.580 MPa and a Poisson's ratio of 0.14 and with a tenacity of 0.574 MPa. Due to the above and considering that with a higher Young's modulus the material will be able to better supports the loads before losing its elastic properties, it is recommended to use the EVA of supplier 3, in addition it is the material that is capable of absorbing more energy before of breakage this indicated in the area under the curve of the stress-strain diagrams.

One of the considerations is that there are differences between supplier-to-supplier formulations probably due to the plasticizers or additives that they add to their mixtures, in addition to the chemical composition and density variation.

4. Conclusions and Recommendations

Knowing different mechanical properties of the materials allows designers and manufacturers to make decisions about the usefulness of the component in the final product, with the values found in this study simulations can be performed to determine the behavior of the material before certain loads, in specific insoles modeling by finite element would allow to know the behavior of the material during the activity. None of the suppliers include these mechanical properties in its technical data sheet, in addition to the fact that there is not much information in the literature. A difference was found regarding the mechanical properties between the latex and the EVA in the tensile test, so although they are used for the same function, the functions for which the footwear component will be required must be analyzed.

It is advisable for product designers to really analyze the efforts to which the insoles will be submitted to choose the appropriate material for the activity. The values found will be used to develop a numerical simulation by finite element to know the behavior of the material with the plantar pressures of a specific population of athletes, in this way the appropriate material to perform the activity will be known.

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References

Apps, C., Sterzing, T., O'Brien, T., Ding, R., & Lake, M. (2017). Biomechanical locomotion adaptations on uneven surfaces can be simulated with a randomly deforming shoe midsole. *Footwear Science*, *9*(2), 65–77. https://doi.org/10.1080/19424280.2017.1293175

Barnes, R. A., & Smith, P. D. (1994). The role of footwear in minimizing lower limb injury. *Journal of Sports Sciences*, *12*(4), 341–353. https://doi.org/10.1080/02640419408732180

García Hernández, M. (2009). La industria del calzado en León Guanajuato México. Análisis, a partir de las economías externas y de urbanización. *Economía Autónoma*, (3), 1–28. Retrieved from http://www.eumed.net/rev/ea/03/mgh.pdf

Goonetilleke, R. (2012). *The Science of Footwear*. https://doi.org/10.1201/b13021

Law, M. H. C., Choi, E. M. F., Law, S. H. Y., Chan, S. S. C., Wong, S. M. S., Ching, E. C. K., … Cheung, R. T. H. (2019). Effects of footwear midsole thickness on running biomechanics. *Journal of Sports Sciences*, *37*(9), 1004–1010. https://doi.org/10.1080/02640414.2018.1538066

Menant, J. C., Steele, J. R., Menz, H. B., Munro, B. J., & Lord, S. R. (2008). Effects of Footwear Features on Balance and Stepping in Older People. *Gerontology*, *54*(1), 18–23. https://doi.org/10.1159/000115850

Perry, S. D., Radtke, A., & Goodwin, C. R. (2007). Influence of footwear midsole material hardness on dynamic balance control during unexpected gait termination. *Gait and Posture*, *25*(1), 94–98. https://doi.org/10.1016/j.gaitpost.2006.01.005

Rocha Aceves, Á. L., & Iglesias Lesaga, E. (2006). La Macrorregión Del Calzado Guanajuatense: ¿ Un Espacio En Transición? *Revista Pueblos y Fronteras Digital*, *1*(1). https://doi.org/10.22201/cimsur.18704115e.2006.1.261

Sekizawa, K., Sandrey, M. A., Ingersoll, C. D., & Cordova, M. L. (2001). Effects of shoe sole thickness on joint position sense. *Gait and Posture*, *13*(3), 221–228. https://doi.org/10.1016/S0966-6362(01)00099-6

Smith, W. F. (William F., & Hashemi, J. (2006). *Fundamentos de la ciencia e ingeniería de materiales* (Cuarta edición.; McGraw-Hill, ed.). Retrieved from https://books.google.com.mx/books/about/Fundamentos_de_la_ciencia_e_ingeniería.html?id=1OPVAAAACAAJ&source=kp_book_description&redir_esc=y