DYNAMIC STUDY OF FOOTWEAR MATERIALS SIMULATING REAL LOADS

A.C. Garcia, J. Ramiro , R. Ferrandis, V. Clement, R.Alepuz, P. Vera, J.V. Hoyos.

Institute of Biomechanics of Valencia (IBV), Spain.

INTRODUCTION

The study of footwear materials has been traditionally based on the determination of the stiffness and the use of the shore A level or in the shock absorbing capacity. In most of the papers only one of those parameters is determined in spite of the relation between them is not clear; a quite soft material does not have necessary to be shock absorbing and a shock absorbing material can be quite rigid. Besides, the study of footwear materials has to face two main problems. The first one is that most of the materials used in footwear under the loads occumng in the sport movements, specially in running or jumping, are no more linear because of the high level of the forces developed in those movements. This means that the rigidity of the material depends on the load and increases with load. The second problem is owed to the viscoelastic behaviour of most of those materials. The rigidity of a viscoelastic material increases as the frequency increases. For these reasons the study of footwear materials must be done by simulating the forces occurring in the movements developed in the sport the footwear is conceived for.

This paper presents a new methodology of study of footwear materials based on the determination of the loads applied and its simulation by means of a dynamic testing machine. Both the rigidity and the shock absorbing capacity of the materials are investigated as a function of frequency. This method permits to know not only the beliaviour of the material in real situations but also which frequencies are the ones preferably absorbed. This is specially interesting because of the general estimation that high frequencies are related with injuries located in the articular cartilage.

A viscoelastic material used in running insoles has been studied and the influence of thickness has been investigated. The results presented are compared with the previously published obtained when the loads applied are perfect sinus waves (Garcia 1991).

METHODOLOGY

The methodology developed by the IBV for the study of viscoelastic materials is based on the determination of the material's complex impedance. The complex impedance of a material is defined as the strength-strain ratio.

$$G(w)=\sigma(w)/\epsilon(w)$$

Considering a harmonic stress excitation, let the strain be given by

$$\sigma(w)=\sigma_0 \sin (wt)$$

Then, the steady-state stress is

$\epsilon(w)=\epsilon_0 \sin(wt-\delta(w))$

beeing $\delta(w)$ the phase shift angle. In complex representation

$$G(w) = \sigma_0(w)/\epsilon_0(w)\, e^{j\delta(w)} = G_1 + jG_2 = \sigma_0(w)/\epsilon_0(w) \cos \delta(w) + j\, \sigma_0(w)/\epsilon_0(w) \sin \delta(w)$$

where G_1 is related to the stored energy in each cycle and G_2 with the lost energy in each cycle. The ratio G_1/G_2 = tg6 is the ratio energy lost/energy stored in one cycle and is usually called "loss tangent". The loss tangent is then a parameter which expresses the shock absorbing capacity of a material. Besides, the modulus of the complex impedance $|G| = \sigma_0(w)/\epsilon_0(w)$ gives the rigidity of the material.

As any given time dependent signal can be expressed as a linear superposition of infinite harmonic signals by means of the FFT transformation, the complex impedance of a material as a function of frequency can be obtained by means of two main methods:

- exciting the materials with succesive harmonic signals of the frequencies required

- exciting the material with any load containing significative components at the frequencies required and compute the FFT of the load and displacement signals. The complex impedance can then be obtained as the transfer function at each frequency defined as the ratio between the components of load and displacement at that frequency.

The second method has the advantage of beeing much more rapid and that the exciting load can be the load measured in real situations.

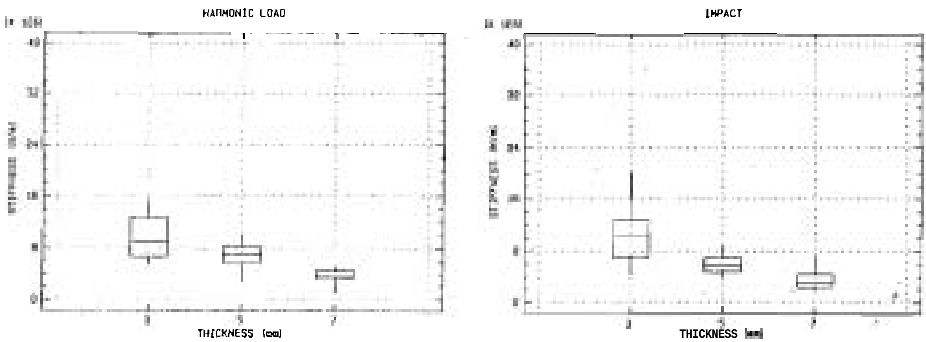
The experiments were carried out by means of a INSTRON dynamic testing machine controlled by a computer. Analogical electric output signals of the load and displacement transducers were obtained from the rear panel of the testing machine console and used as input signals for a FFT Spectrum Analizer to obtain the load and displacement spectrums and the transfer function (equivalent to the complex impedance) as a function of frequency. From the amplitude of the transfer function the rigidity can be obtained and the tangent of the phase shift between load and displacement is directly the loss tangent (the rate of energy lost to the energy stored).

The impact signal was a load of 250 Kg applied in 12 mseg, similar to the loads obtained with a force platform in running. Mean values of 8 consecutive impacts were considered for each measure in each test sample. The samples had an area and a shape similar to the area in contact with the heel. Three samples of each thickness were measured in order to investigate the dispersion of the test.

RESULTS AND DISCUSSION

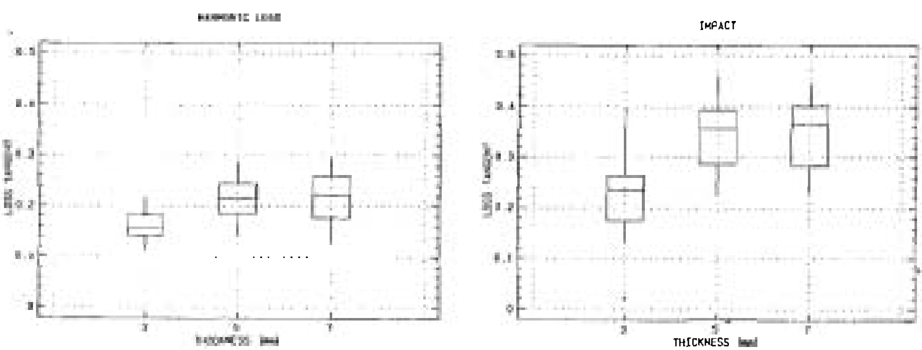
Results previously published obtained with the sinusoidal test (Garcia A.C. 1991) show that while the rigidity always increases with frequency with a rate depending on the material, the shock absorbing capacity variation with frequency depends on the material. The results of the shock absorbing capacity of the material as a function of thickness show that as the thickness increases the shock absorbing capacity increases too. For the rigidity, the influence of the thickness in the bottoming out of the material is clearly showed. The thickness analysis also shows that it is possible to obtain a optimum thickness determined when a thicker material does not mean a significant increase in shock absorbing capacity and a lowering of rigidity.

In figures 1 and 2 those results are presented comparing them with the results obtained with the impact test. In figures 1 the results for the rigidity as a function of thickness are presented. **As** it is shown in this figure the general behaviour and the values obtained with both methods are very similar. For the loss tangent (figures 2), although the general behaviour obtained with the two methods is very similar, the values are not the same beeing higher the results obtained with the impact test.



a) b)

Figure 1: Results obtained for the rigidity as a function of thickness with sinusoidal load a) and with impact load b).



a) b)

Figure 2: Results obtained for the loss tangent as a function of thickness with sinusoidal load a) and with impact load b).

The results of the rigidity and loss tangent as a function of frequency obtained with the two methods show that, although the general behaviour is similar with both methods, a more significant change of the loss tangent with frequency is obtained with the impact load.

CONCLUSION

The results obtained with the two methods proposed show that both methods produce similar results and so any of them can be used for determining the complex impedance as a function of frequency if comparisons between materials is the objective. As the results show differences in the values of loss tangent, results obtained with different methods can't be compared. Differences of the loss tangent results obtained with the two methods presented can be due to nonlinearity of the material.

The variation with frequency encountered in both the loss tangent and the rigidity, supports the idea that the determination of the characteristics of the materials must be done as a function of frequency or at least by means of loads with time history similar to those occumng in real situations. If the above mentioned is not considered, a material that was supposed to be quite soft under the test applied can result to be very rigid for higher frequencies (Gross 1989).

ACKNOWLEDGEMENTS

Authors want to thank the ClCYT (Comisión Interministerial de Ciencia y Tecnología) and the TERCONSA company the financial support for this work.

REFERENCES

Gross T.S., Bunch R.P. (1989). Material moderation of plantar impact stress. Medicine and Science in Sports and Exercise, vol 21 No 5, pp 619-624.

Clarke T.E., Frederick E.C. (1981). Dynamic load displacement characteristics of athletic shoe midsole materials. American Society of Biomechanics Meeting.

Nigg B.M. (1990). The validity and relevance of the tests used for the assessment of sports surfaces. Medicine and Science in Sports and Exercise, vol 22 No 1, pp 131-139.

Garcia A.C., Ramiro J., Navarro E., Ferrandis R., Gianikelis K., Vera P., Hoyos J.V. (1991) Dynamic analysis of footwear materials. Second IOC World Congress on Sport Sciences. pp 188.