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Viscoelasticity of Multi-layer Material Systems used in Soccer Balls

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ABSTRACT

The impact characteristics of sport balls have been investigated by a number of authors covering a wide number of sports which employ both hollow pressurised balls [1-2] and solid balls [3]. A Rayleigh based damping co-efficient is typically used in order to introduce energy loss within the model. However, this cannot be physically determined directly and is often used in numerical simulations as a fitting parameter to enable model agreement with experimental results. To develop accurate soccer ball FE models there is a distinct need to determine viscoelastic material properties experimentally to enable direct input into the model to allow for sufficient modelling accuracy to depict kinetic energy loss characteristics.

A dynamic mechanical analysis (DMA) [4] was used to determine viscoelastic properties of the constituent multi-layer material components of two modern day ball types, ball A and ball B. Ball A outer panels consist of an Ethylene-propylene-diene-monomer (EPDM) foam, a woven fabric layer, and a thermoplastic polyurethane (TPU) outer layer. Ball B outer panels consist of a polyurethane (PU) foam and a TPU outer skin layer only. Measurements of tensile based storage (*E'*) and loss (*E''*) moduli were carried out in addition to *tan δ* which is the ratio: *E''/ E'* and provides a measure of material damping. Testing occurred throughout a frequency range of 0.1 – 100 Hz. Fig.1 gives details of repeat test average *tan δ* values for the outer panels of both ball types. It is shown that ball B exhibits higher levels of material viscoelasticity than ball A for higher strain rates, i.e. test frequencies of 10 and 100 Hz.

	Frequency (Hz)			
	0.1	1	10	100
Ball A	0.129	0.120	0.121	0.210
Ball B	0.108	0.107	0.146	0.565

Fig 1 –Tan δ for outer panels materials of balls A and B.

A series of normal impacts occurred whereby each ball type was impacted against a steel plate such that inbound ball trajectory was perpendicular to the plane of the plate. Impacts occurred at inbound velocities of 9, 14, 22 and 32 ms^{-1}. Each ball was pressurised to 1 bar, five balls were used per type and five impacts occurred for each ball. Each impact was recorded using a high speed video (HSV) camera and each audio video interleave (AVI) file was digitised using image processing software to enable the determination of the co-efficient of restitution (COR). COR is the ratio of rebound to inbound velocity and is considered to be strongly related to material damping [5].

An FE model of each ball design was developed using the Abaqus EXPLICIT software package. Each model utilised linear-interpolation composite shell elements to allow a through-thickness composite structure of the panels to be sufficiently modelled. Pressurisation of each model was permitted through the use of a mass flow rate imparted onto a cavity reference node which was coupled to an integral layer of hydrostatic fluid elements that shared the nodes of the structural shell elements. The DMA data as exemplified in fig. 1 was used to define material viscoelasticity for the constituent layers of both ball FE models by defining real and imaginary values based on *E'* and *E''* respectively. Each ball model was pressurised to 1 bar and impacted against a rigid surface that was constrained with regard to all degrees of freedom. Fig. 2 provides data for COR and the maximum deformation point for a 32 ms^{-1} impact for both model and experimentation.

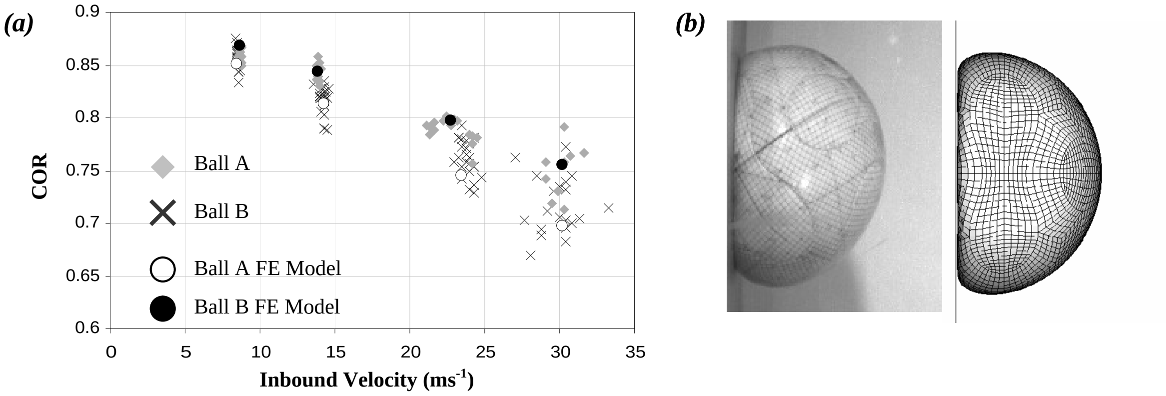

Fig 2 – (a) COR and (b) maximum deformation point comparisons between model and experiment.

It is shown that agreement between model and experimentation is within 3%. The differences in the magnitude of COR between both ball types are reflected in the models. Ball type A, which was found to have lower levels of material damping gave lower levels of COR, and the inverse being true for ball B. The FE models also reflected differences in the COR/Inbound Velocity gradient which was found to be higher for ball A. The results indicate the importance of the outer panel material used within new generation ball types as a principal energy loss mechanism. This study has provided a framework to estimate the kinetic energy loss linked with material viscoelasticity making a basis for an improved understanding of the dynamic properties of soccer balls.

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