Developing finite element models of current, elite soccer balls

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Introduction

Soccer is the most popular global sport, with over 265 million active players [1]. Finite element (FE) simulations enable investigation of new ball designs and material advances. Current FE models from Price *et al* [2] and Taha & Hassan [3] describe balls with an inner bladder and outer panels; however, modern designs use an integrated rubber bladder and polyurethane covering. This study experimentally investigates modern, elite balls to generate a new material model and a validated FE simulation.

Materials & Methods

Three elite-level ball designs were selected for testing. Multiple versions of each were available, affording some to be cut into coupons for characterisation. Dumbbell specimens were cut to Type 3 dimensions, due to the limited size of each panel. Tensile testing was performed using an electromechanical uniaxial testing machine (Zwick Z50; Ulm, Germany) with a 1kN load cell and non-slip grips [4]. Crosshead speeds of 100mm/min and 300mm/min captured low strain rate behaviour, whilst minimising the effect of strain rate sensitivity. Each crosshead speed was repeated at least 4 times. To capture the viscoelastic effects evident during ball impact, the tensile test geometry was used to measure stress relaxation. Single-step stress extension was performed at a maximum cross-head speed (600 mm/min) to a strain of 0.25 and followed by a 100 s relaxation period. These data enabled definition of hyperelastic and viscoelastic unique material models for each ball.

A machine (Globus Euro Goal 3000; Codogne, Italy) was used to launch balls at a rigid steel anvil, at velocities between 11-20ms^{-1}. All balls were inflated to a range of pressures (0.8, 1.0, 1.2 bar), covering the FIFA quality programme specification [5]. All impacts were recorded on a high-speed camera (Edgertronic SC1; Sanstreak Corp, USA), positioned to capture the perpendicular axis at the anvil, operated at 1.5kHz with a resolution of 688 x 544 pixels. Two LED light banks provided illumination. Slow-motion analysis software (Photron Fastcam Viewer, Tokyo, Japan) was used to manually extract maximum longitudinal deformation, contact time, inbound velocity, and outbound velocity for validation.

Each ball was then created within the sketch module of Abaqus FE software (Dassault Systemes, France), meshed using composite shell elements [3] and had

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applied the relevant material model. The surface-based fluid cavity method was used to achieve ball pressurisation. Pressure and velocity were applied to the ball using boundary conditions. Simulations were then run replicating the experiment, recording contact time, longitudinal deformation, and coefficient of restitution.

Results & Discussion

Material characterisation provided data across the 3 balls, for 2 uniaxial loading rates and 1 tensile stress relaxation loading rate, to produce ball-specific stress-strain data (fig1. (a, b)). A material model was also then defined for each ball by fitting experimental data to the available hyperelastic and viscoelastic constitutive models, before being evaluated by calculating the relative difference. Computational simulations achieved encouraging comparison with experimental data (fig. 1(c)).

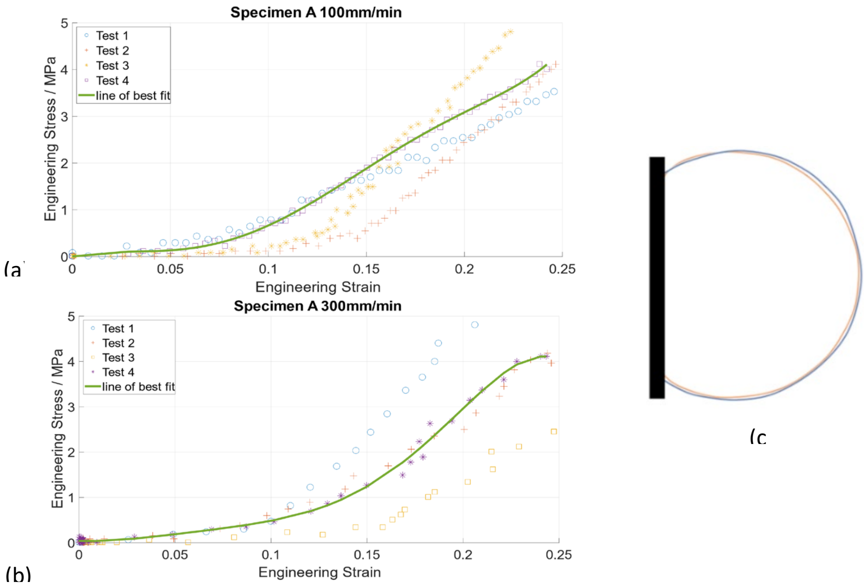

Fig 1: Uniaxial stress-strain data at (a) 100mm/min and, (b) 300mm/min crosshead speed (c) Schematic comparison showing maximum ball deformation during FE simulation (orange) and high-speed video analysis (blue) during impact at 11.67ms^{-1}, inflated to 0.8bar.

Conclusion

A new FE model of an elite ball now provides a validated platform for further investigation into new designs and ball interactions.

References

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