Method development for compression testing of synthetic ballistic gelatine

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Abstract. This paper reports on the development of a test method for compression testing of 10% synthetic ballistic gelatine. The method uses imaging techniques to measure the non-uniform specimen deformation of the gelatine initiated by friction at the sample-plate interface. Based on past work, initial computational models were produced to estimate the required force and displacement ranges and specify the testing platform. Digital Image Correlation was used to give a unique insight into the full field deformation of the specimens improving the material characterisation results and insight.

Introduction

Organic gelatine, with a concentration of 10% gelatine at 4°C, is considered an acceptable simulant of human soft tissue, with reasonably representative mechanical properties [1]. Synthetic gelatine overcomes the storage requirements, variability and shelf life limitations of organic gelatine [2-3], and may be reusable (at least for a few cycles). However, there is a wide range of reported mechanical properties for 10% gelatine, including work that observed non-uniform deformation within the soft materials during low strain rate compression testing [4]. As synthetic gelatine offers greater potential for batch-to-batch consistency, comprehensively characterising its material properties will provide baseline data for modelling and protective design, if the non-uniformity in its deformation can be measured. This paper reports on a technique that films the specimen response and uses digital image correlation (DIC) to ascertain the deformation and strain fields during the experiment.

Experimentation

Specimen design and manufacture. The synthetic gelatine arrived as a premade block (16” L x 6” W x 6” H). Pieces of gelatine were removed from the block and carefully weighed to the correct mass. These pieces were placed in a purpose-built mould to produce 25mm diameter cylindrical specimens with a height of 25 mm. The mould was heated to 125 °C for 4 hours, then left to cool overnight. The completely cooled specimens were painted using highly flexible white paint. An airbrush was used to achieve a smooth opaque finish. Once dry, the curved surface was printed with black speckles in a random pattern.

Quasi-static compression test arrangement. The test technique involved using a Shimadzu universal compression test frame to apply quasi-static compression to the cylindrical specimens, similar to the method used in references [1, 4]. The tests were displacement controlled, with a constant nominal cross-head speed of 30 mm/min. The deformation was filmed using 5MP high resolution stereo cameras with the field of view side onto the specimen, as shown in the schematic in Fig. 1. DIC was performed using Correlated Solutions VIC3D software. Four repeat tests were performed.

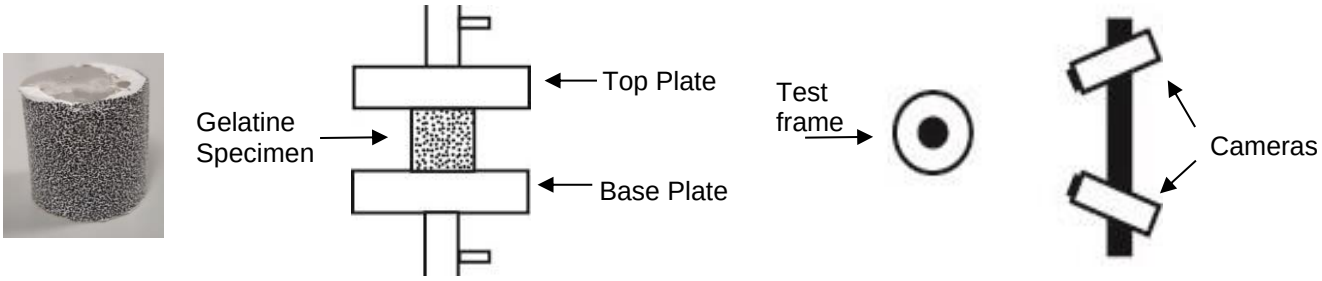

Figure 1: Test arrangement

High strain rate compression test arrangement. High strain rate tests are planned using a Split Hopkinson Pressure Bar configuration, with different strain rates achieved by altering the striker velocity.

Computational Simulations

To facilitate choices in the test arrangement (such as cross-head speed, displacement cut-off, load cell force range and Hopkinson bar materials), compression of gelatine specimens was simulated using LS-Dyna.

Model description. 2D axisymmetric simulations of quasi-static compression at a nominal strain rate of 0.01 s^{-1} of gelatine cylinders were performed. The nodes at the base of the cylinder mesh were fixed in the y direction (height) to represent the fixed bottom test plate. A constant velocity was applied to the top nodes in the negative y direction to represent the moving top plate. The gelatine was modelled as a simplified rubber/foam in LS-Dyna (MAT181). This material card was used by Singh and Bari [5] to model lower limb soft tissue under explosion loading and is used in the Total Human Model of Safety [6]. The stress-strain data recorded by Cronin [1] was used as the input load curve for the model. Young's modulus (E) was estimated from the data plotted in Fig. 2 [1, 4]. This value of E was used to calculate the bulk modulus (K). The density and Poisson's ratio (υ) were estimated from our block of gelatine.

Density (kg/m^3)	E (kPa) [1,4]	K (MPa)	υ
986	150	83.33	0.499

Table 1: properties of gelatine used in the MAT181 material card

Simulation results. The true stress - true strain curves obtained from the simulations were compared to similar experiments (on organic 10% gelatine), and reasonable agreement was obtained, as shown in Fig. 2. The assumed properties in the current model are not expected to perfectly match the experimental results. However, the shape of the curve gives confidence in the choice of MAT181 as a model for gelatine. The actual experimental results will be used to optimise the model once the high-strain rate tests are completed. The simulation results were used to determine limits to the experiments and ensure a sensitive enough load cell was used for the quasi-static compression tests, given the highly pliable nature of gelatine as a soft material. The small true stress values (below 200 kPa) indicate that polymeric bars will be the best option for the Hopkinson bar material.

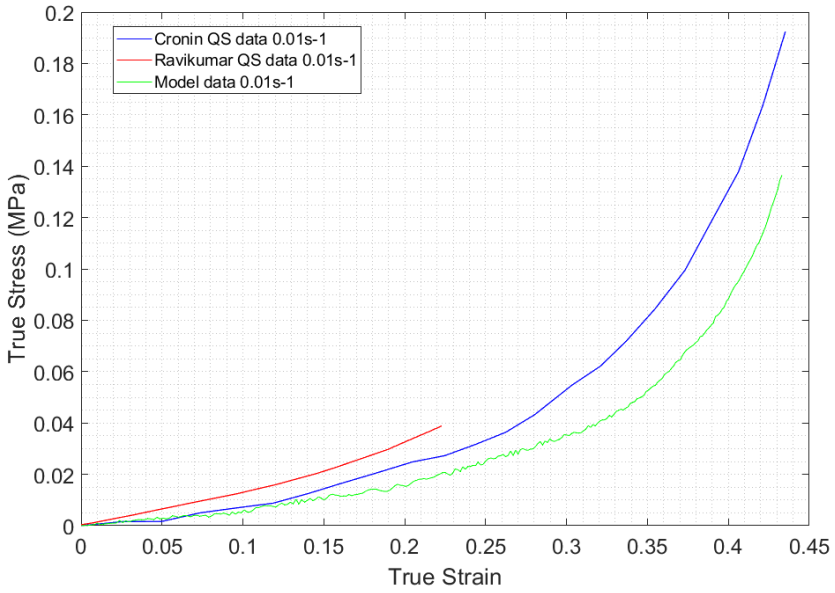

Figure 2: Simulated true stress- true strain curves for synthetic gelatine obtained using MAT181, compared to experimentally obtained curves for 10% organic gelatine [1, 4]

Conclusion

The material tests performed helped bridge the gap in the literature producing material characterisation parameters that were validated in the numerical models. These parameters, once validated for the full strain rate of expected loading conditions the material should experience, will help inform the different human protection tests where it can be used as a human surrogate material.

References

[1] D.S. Cronin and C. Falzon, Expt. Mech., Vol. 51 (2011), p.1197-1206.
[2] J. Read, R. Hazael and R. Critchley, Appl. Sci., Vol. 12 (2022) 4954.
[3] N.R. Maiden, The assessment of bullet wound trauma dynamics and the potential role of anatomical models, PhD thesis (2015).
[4] N. Ravikumar, C. Noble, E. Cramhorn and Z.A. Taylor, J. Mech. Behav. Biomedical Mater., Vol. 47 (2015) p 87-94.
[5] B. Singh and M.A. Basri, Human Factors & Mech. Engng for Defense & Safety,Vol. 6:14 (2022).
[6] Total Human Model for Safety (THUMS), Toyota. Online, available at: https://www.toyota.co.jp/thums/about/.