Quantifying Uncertainty in Materials Strength

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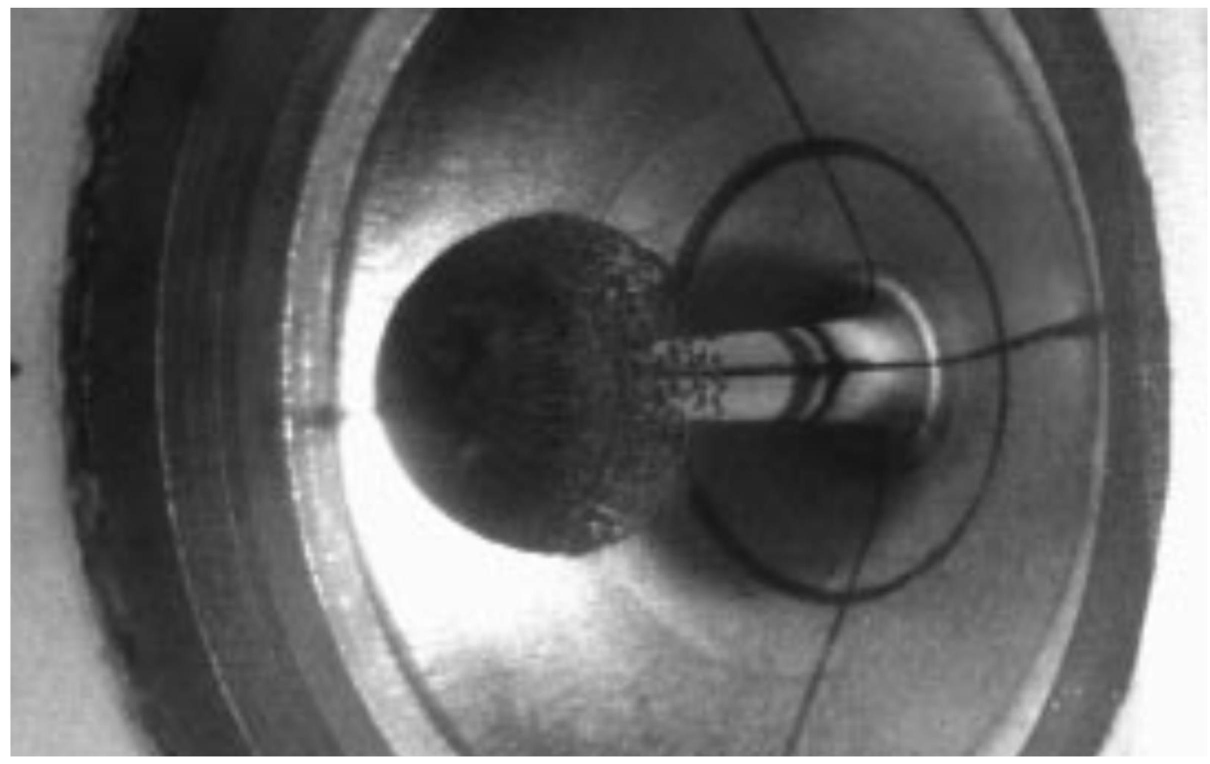
Abstract

A Bayesian approach is used to calibrate a strength model to Taylor impact data.

Introduction

Quantifying uncertainty in model predictions is a motivating factor. Many experiments depend on simulations to estimate variables that can not be measured directly, thus prompting the need to determine the uncertainty in their predictions.



In shaped charge experiments values such as temperature rise and strain rate must be inferred from models. Image from *Science and Technology Review 1998*.

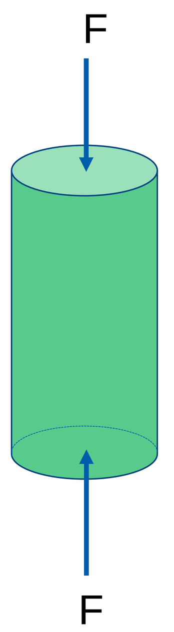
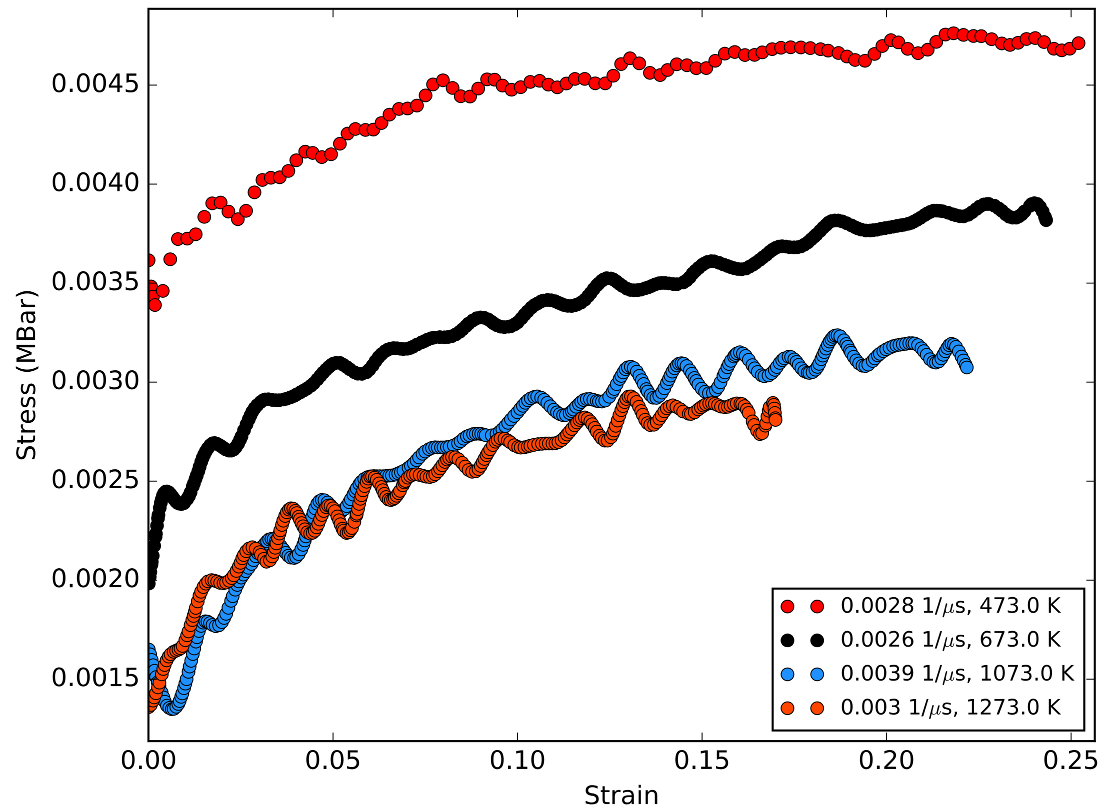


Illustration of compression specimen.

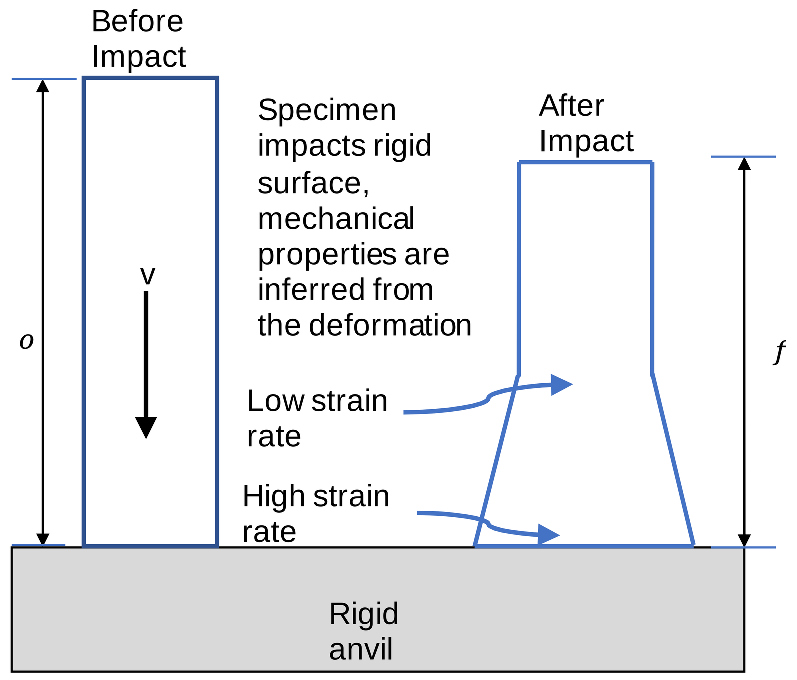


Hopkinson bar stress-strain curves for Ta at various temperatures and strain rates.

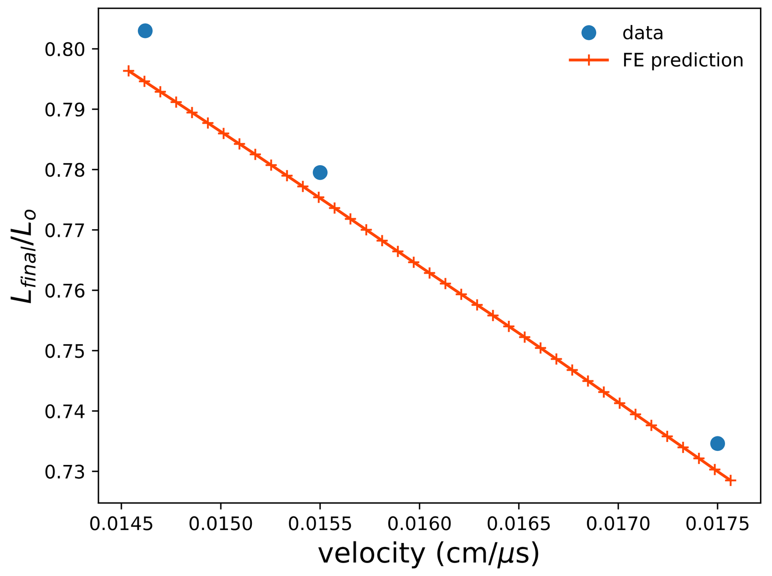
Traditionally stress-strain data such as that presented here is used for calibration of materials strength models. However, such data is limited to strain rates of ~ 10^3 1/s, in order to get more reliable prediction of strength at higher strain rates consideration of additional experimental data is needed.

Taylor Impact Test

Strength data at higher strain rates generally does not measure the stress-strain response directly.



Taylor impact experiments provide information on strength at strain rates ~ 10^4 1/s.



QoI in Taylor impact experiment as a function of impact velocity.

Strength Models

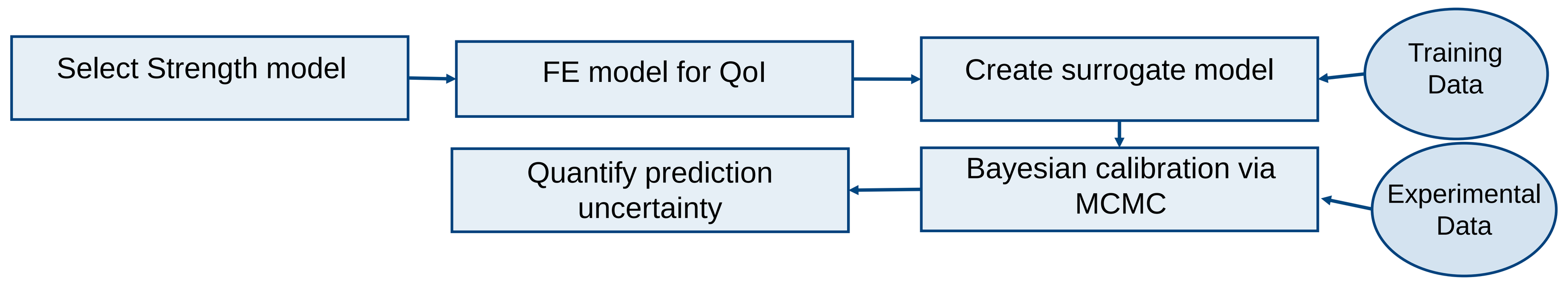
Predict the stress-strain response of a material, range in complexity from simple such as Johnson-Cook to relatively complex such as MTS.

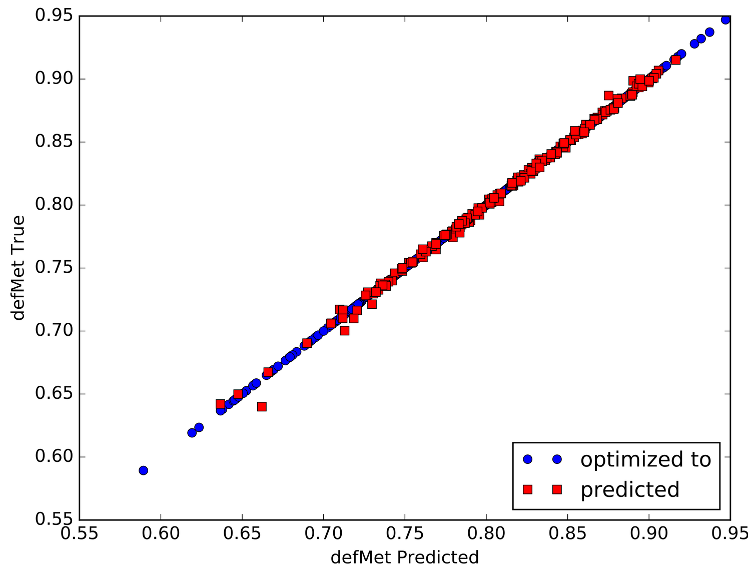
$$\sigma_{flow} = \mathrm{f}(\boldsymbol{x}_i, \boldsymbol{\theta})$$
$$\boldsymbol{\theta}_{JC} = \{A, B, C, m, n\}$$
$$\boldsymbol{\theta}_{MTS} = \{q_i, p_i, \hat{\sigma}_{s0}, g_{0i}, \sigma_i, \ldots\}$$
$$\boldsymbol{x}_i = \{velocity\}$$

Parameter A calibrated for JC

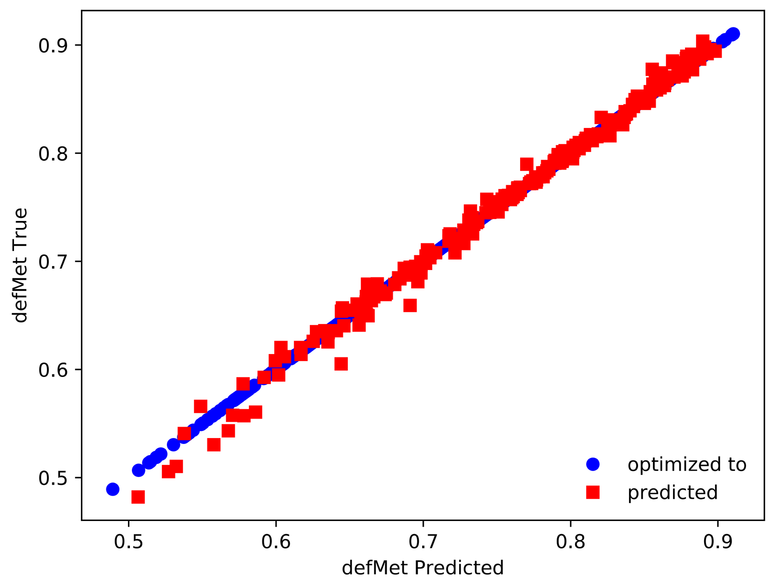
Parameter q_i calibrated for MTS

Bayesian Approach With Surrogate



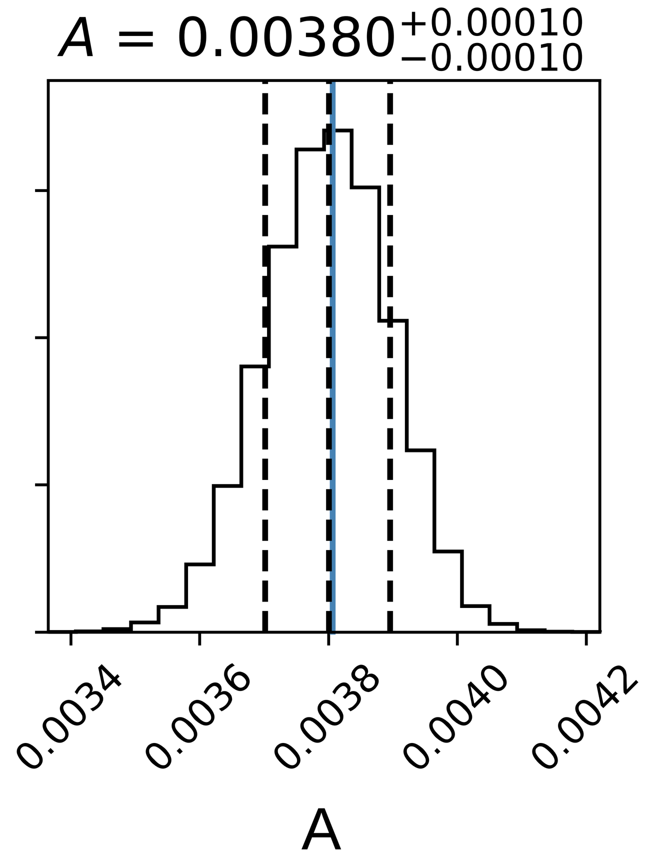


JC model cross-validation.

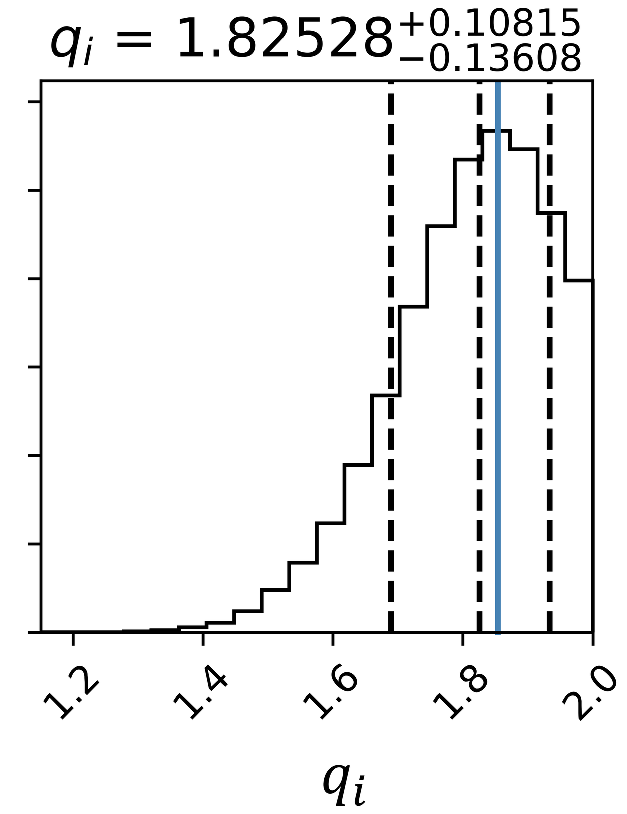


MTS model cross-validation.

Posterior Distribution



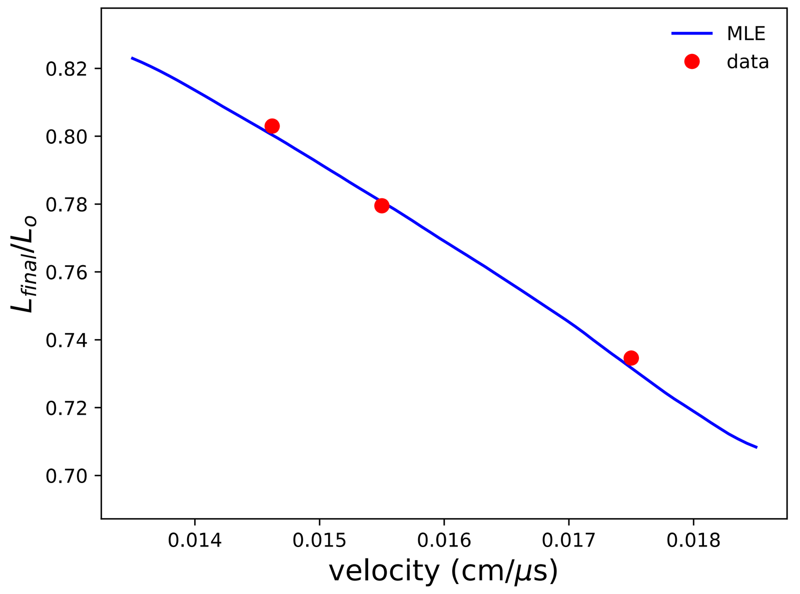
Posterior distribution for JC model parameter A, showing Gaussian behavior.



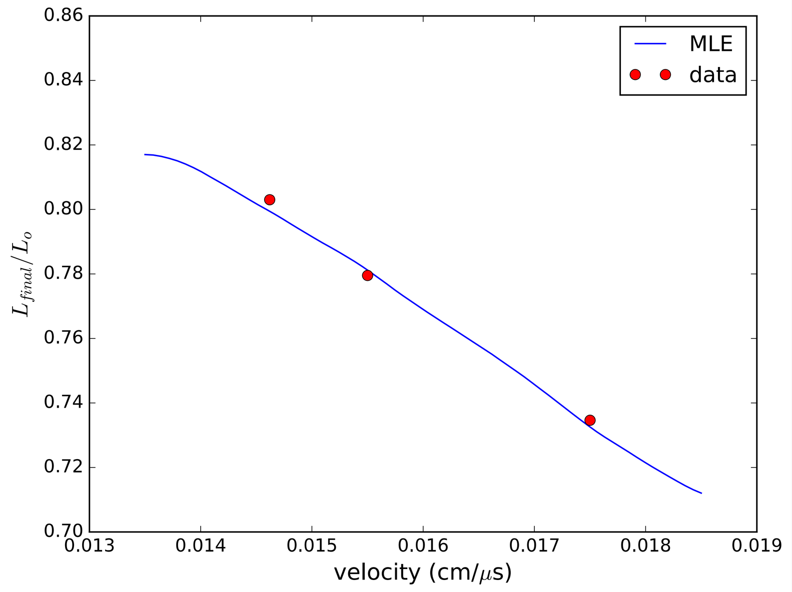
Posterior distribution for MTS model parameter q_i.

Propagation of Uncertainty

Posterior distribution sampled and propagated through the surrogate for an uncertainty estimate.



Uncertainty propagation through the JC Model. Hashed lines indicate 95 % credible interval



Uncertainty propagation through the MTS Model. Hashed lines indicate 95 % credible interval

Conclusions

- Greater variability in MTS model than JC, likely due to increased complexity in the MTS model relative to JC.
- Project combines knowledge base of materials science, statistics, and HPC.
- Future work: will focus on combining disparate data sets into the calibration routine.
- Future work: calibration using cylinder profiles at constant impact velocity.

GP based surrogate models useful tool in estimating uncertainty in materials strength

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