

Material plastic properties characterization using a genetic algorithm and finite element method modelling of the plane strain small punch test

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Background

Plane strain small punch test tool design

**Finite element model for the plane strain
small punch test**

**A Genetic Algorithm for material
characterization**

Results

Conclusions and future work

Background

Material characterization

Safe design;

Full use of strength;

Life-time extension: leads to cost saving,
environment friendly.

Before 2000

Manahan, et al. at MIT in 1981 for the studies of the post irradiation mechanical properties;

Baik et al. to investigate the ductile-brittle transition temperature in 1983.

Schwant et al. established the relationship between the FATT and fracture toughness, in 1985.

Mao et al. in Japan during 1980s led to the recommended practice for small punch testing of metallic materials.

Foulds et al. further extended their research by introducing the strain energy density concept for fracture failure assessment.

Parker, J.D. et al. creep studies

Review paper

Tom Hyde, Wei Sun, J.A. Williams,

“ Requirement for and use of miniature test specimens to provide mechanical and creep properties of materials: a review”. *International Materials Reviews*, 2007, Vol. 52, No. 4, pp213-255.

Roger Hurst, Valerio Bicego and Jude Foulds, “Small punch testing for creep – progress in Europe”, *Proceedings of CREEP8, eighth International conference on creep and fatigue at elevated temperatures*, 2007, Texas.

Yingzhi Li, Keqin Ding, Gang Chen and Binan Shou

“Research Status and Prospects for small punch testing technique”.

Material plastic parameters characterization

Trial and error method

Optimization method

Genetic algorithm,

Neural network method, Martin Abendroth, et al., 2003, 2006

Inverse FEM method, Asif Husain, et al., 2004

Why plane strain SPT?

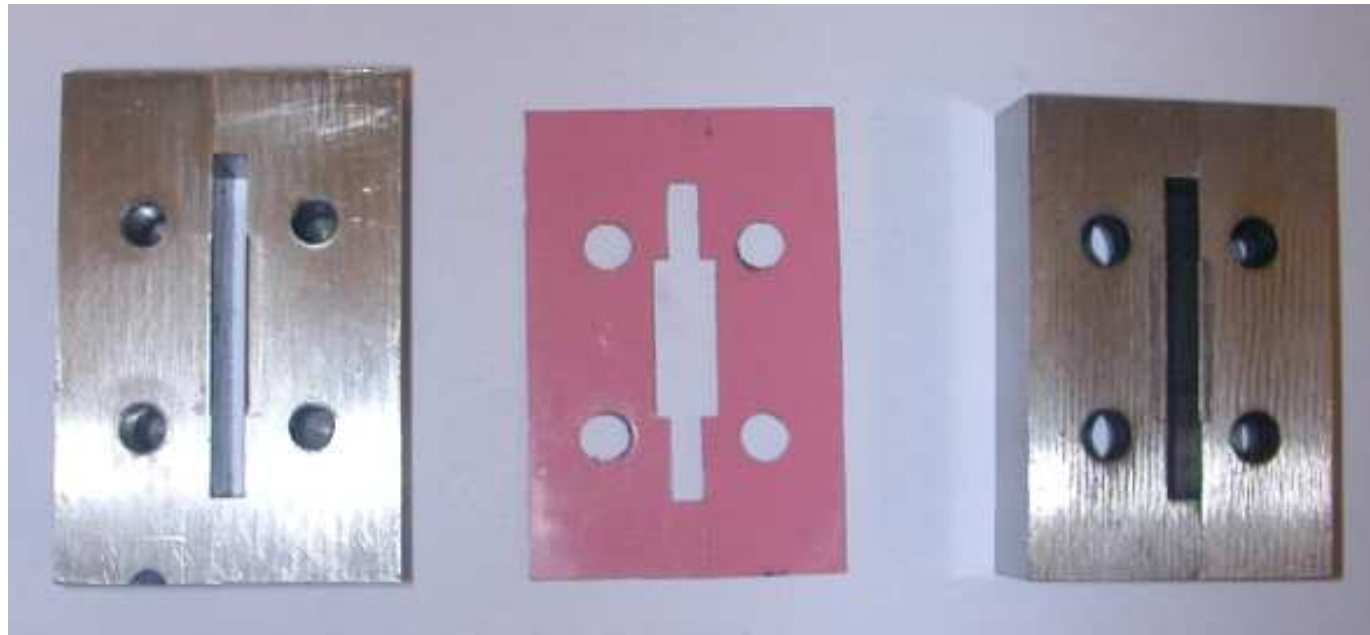
Some problems with existing SPT

Welded components: different zones
Heat affected zone; Thermal mechanical

Shape of the punch head: hemispherical or
spherical ball

Plane strain small punch test tool design

Components: Top die; bottom die;



(a) Bottom die

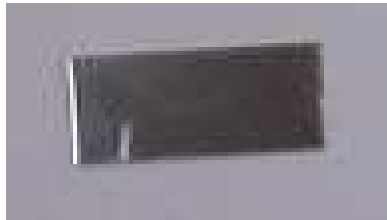
(b) Shim

(c) Top die

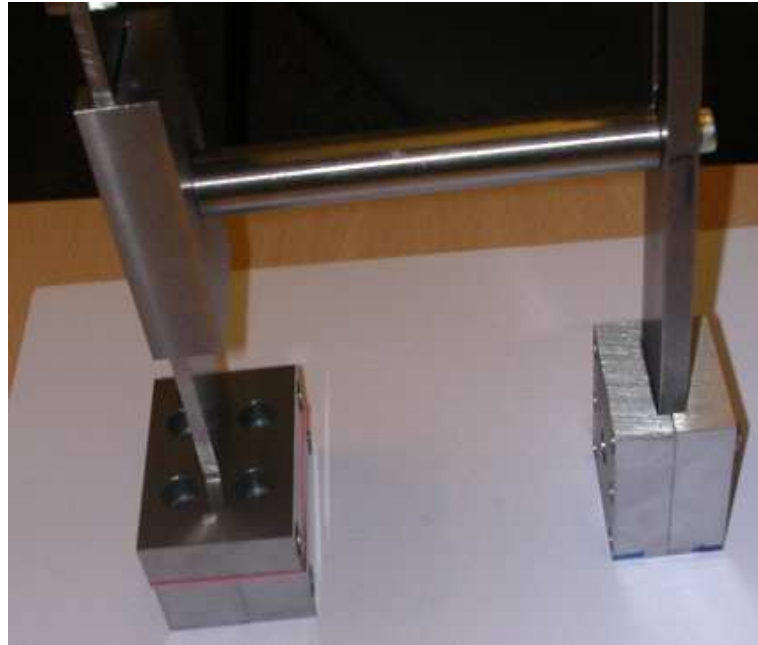
Small punch plane strain testing



prism with a half-circular shape



(d) Specimen



(e) Assembly of the plane strain test

Ramberg-Osgood material constitutive relationship

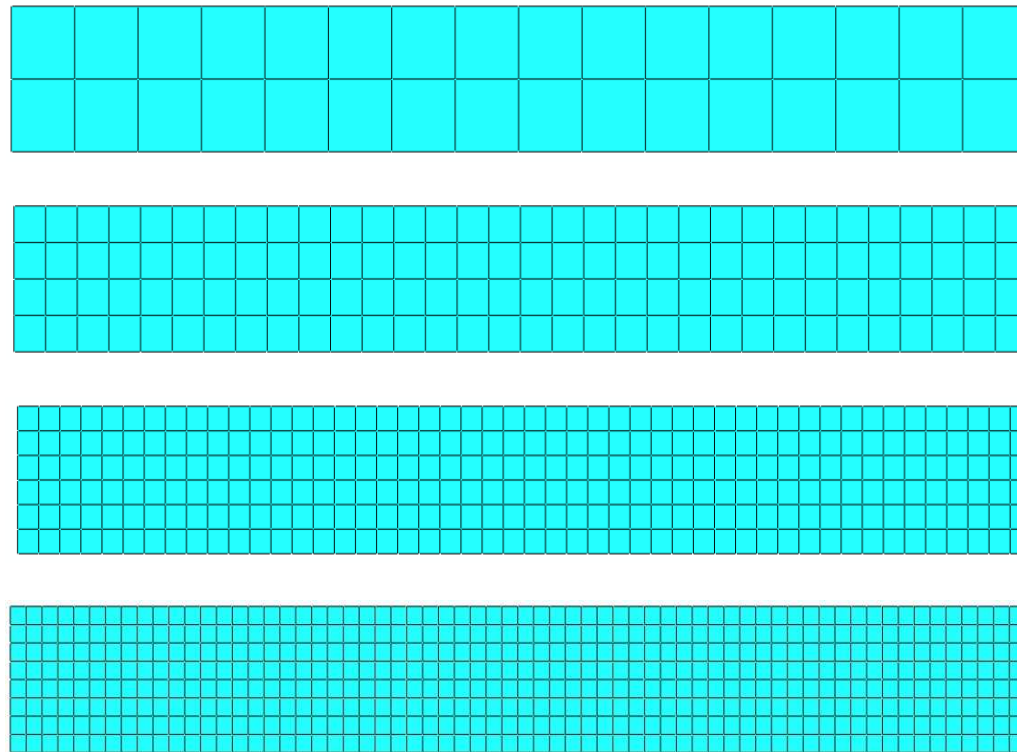
$$\varepsilon = \frac{\sigma}{E} + K \left(\frac{\sigma}{E} \right)^n$$

$$\alpha = K \left(\frac{\sigma_{0.2}}{E} \right)^{n-1} \quad \alpha * \frac{\sigma_{0.2}}{E} = 0.2\%$$

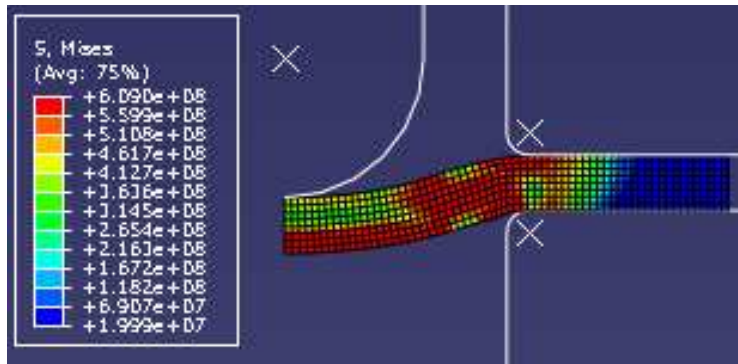
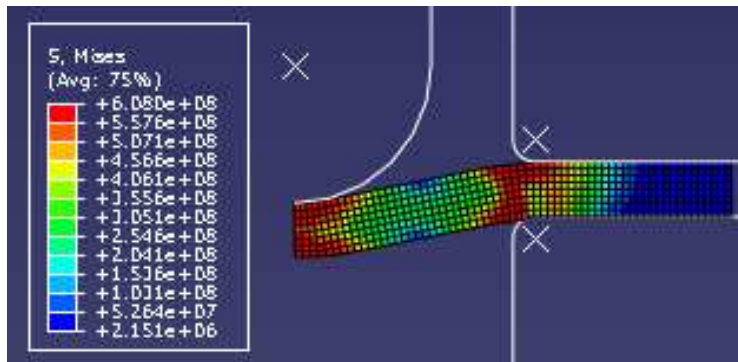
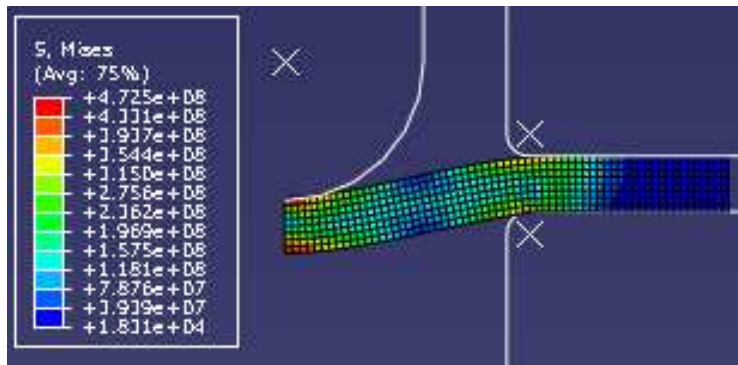
$$\varepsilon = \frac{\sigma}{E} + 0.002 * \left(\frac{\sigma}{\sigma_{0.2}} \right)^n$$

n , α are material parameters to be evaluated

Finite element model for the plane strain small punch test



FEM meshes used for convergence tests: from (a) the coarsest to (d) the finest



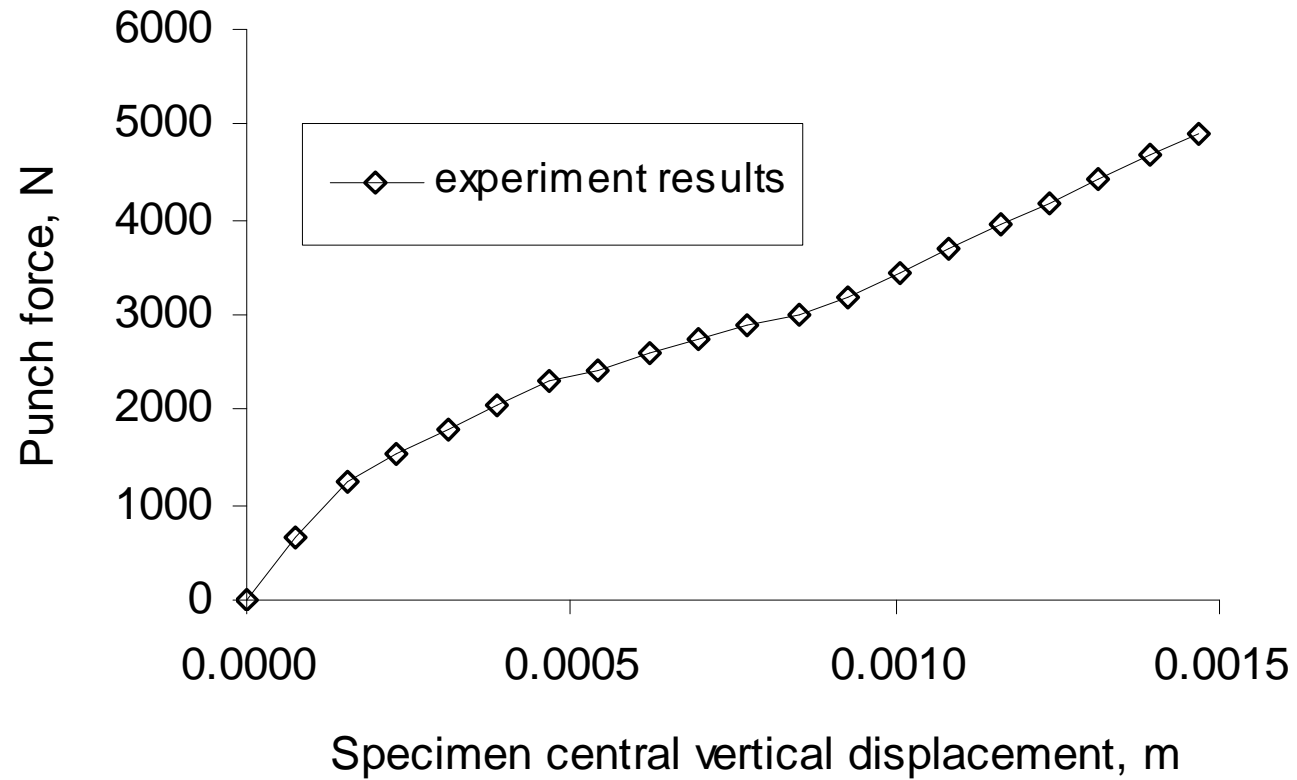
Stress contours at
different deformation
stage

Experimental results



The deformed specimen

Punch force vs displacement



Punch force varies with specimen central vertical displacement

- The fitness function used in this paper was assumed as

$$f = \frac{1}{0.01 + \Phi}$$

where Φ is the square root of the average of the sum of the squares of the relative error between the experimental and the simulated punch forces corresponding to the pre-set specimen central line displacements

Genetic Algorithm results

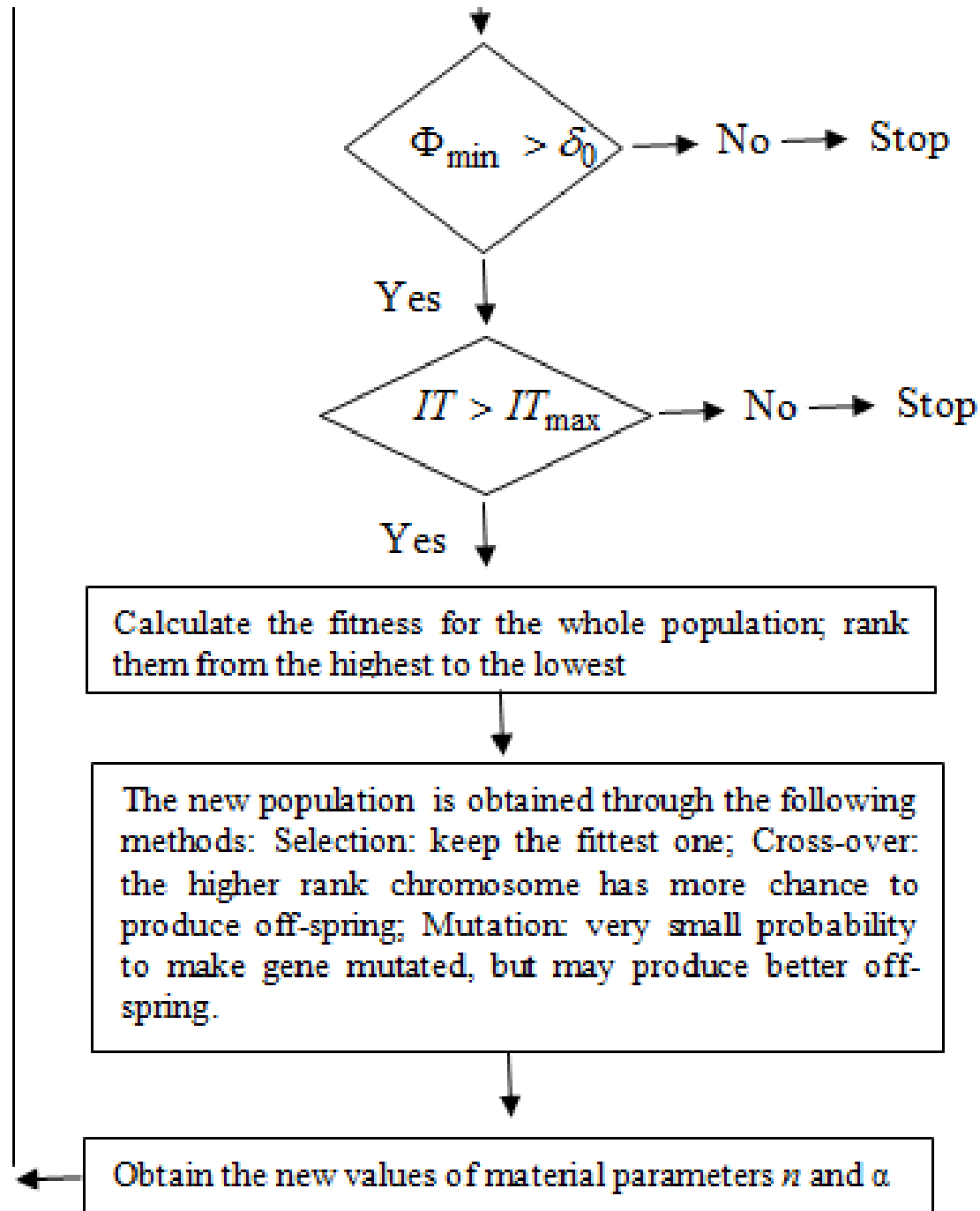
Set the total size of population; initialize the values of material parameters n and α ; build the plane strain SPT FEM model

Calculate the stress plastic strain data for each individual chromosome and perform the ABAQUS simulation for each chromosome; obtain the punch force and specimen central line vertical displacement

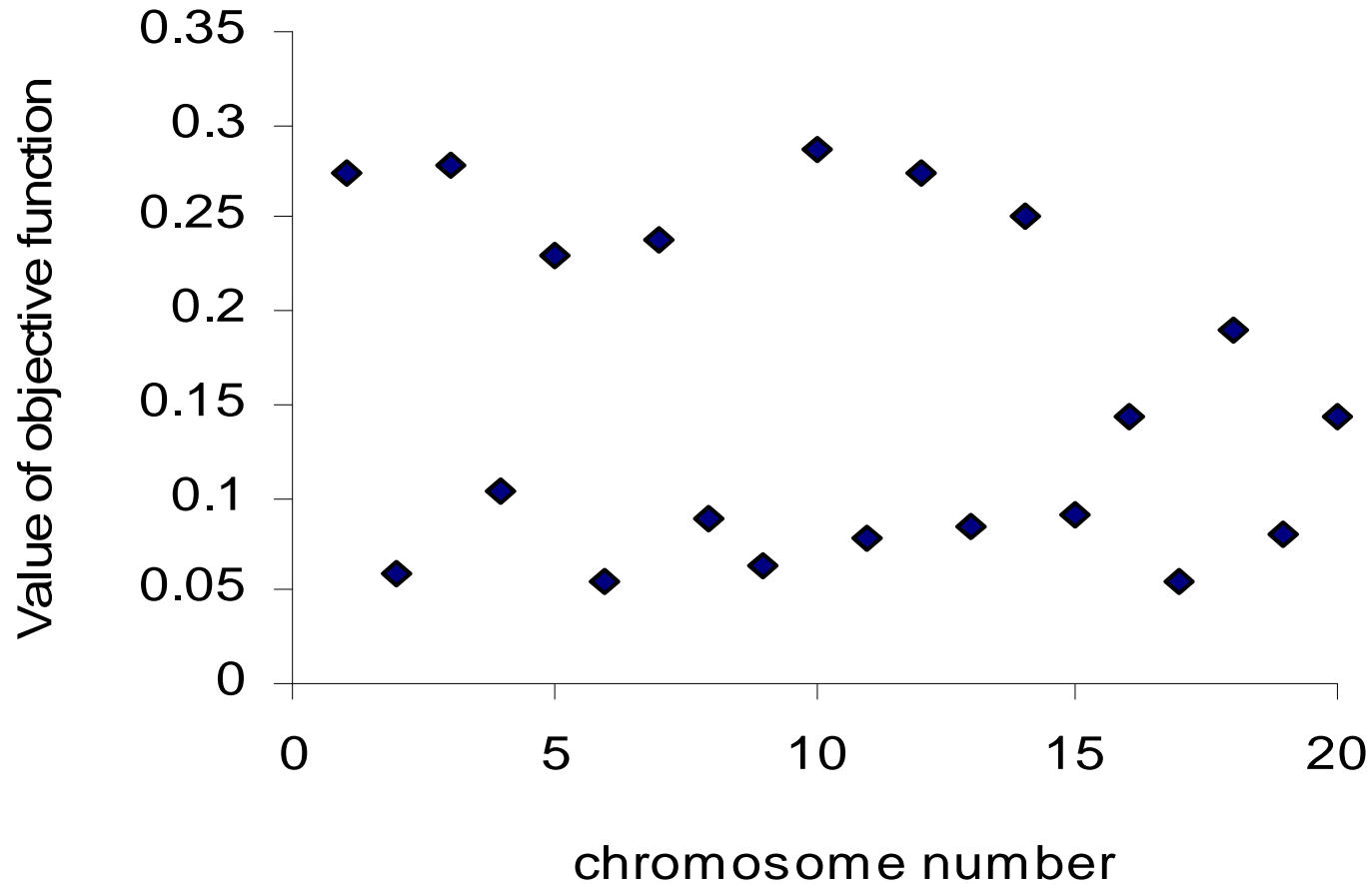
Calculate the objective function

$$\Phi = \sqrt{\frac{1}{m} \sum_{i=1}^m \left(\frac{F_i^{\text{exp}} - F_i^{\text{cal}}}{F_i^{\text{exp}}} \right)^2}$$
 for each

chromosome, find the minimum one as Φ_{\min}

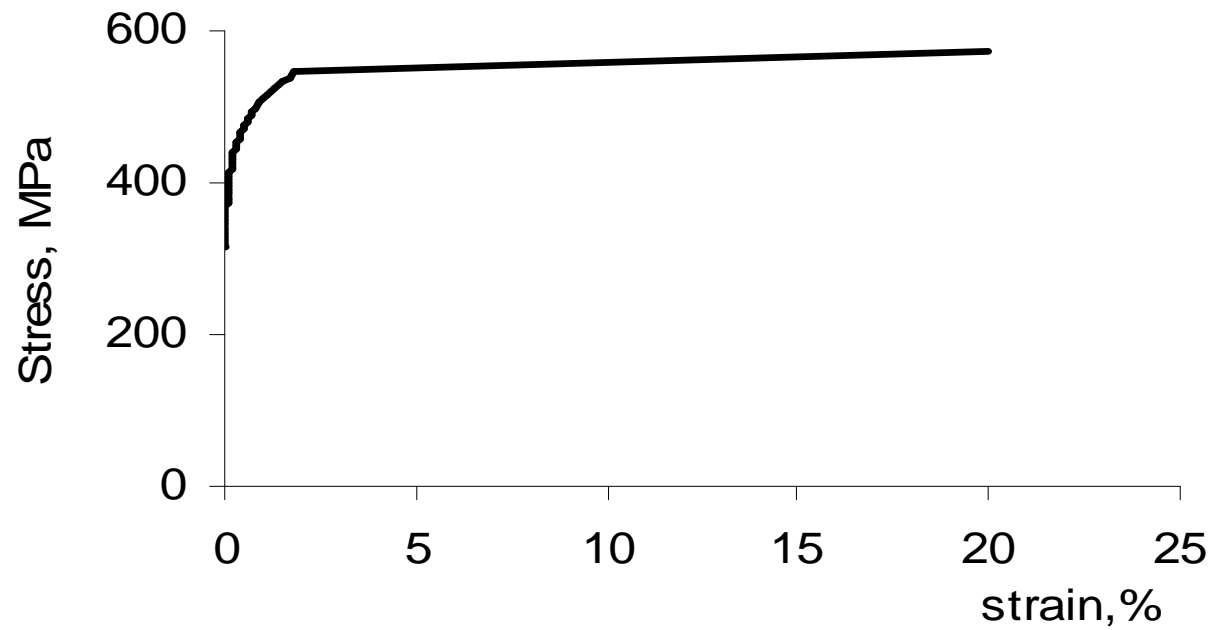


The cross-over probability was set as 80% while a relative large mutation rate of 0.05 was specified due to the small population (seed number: 20) used in this simulation.

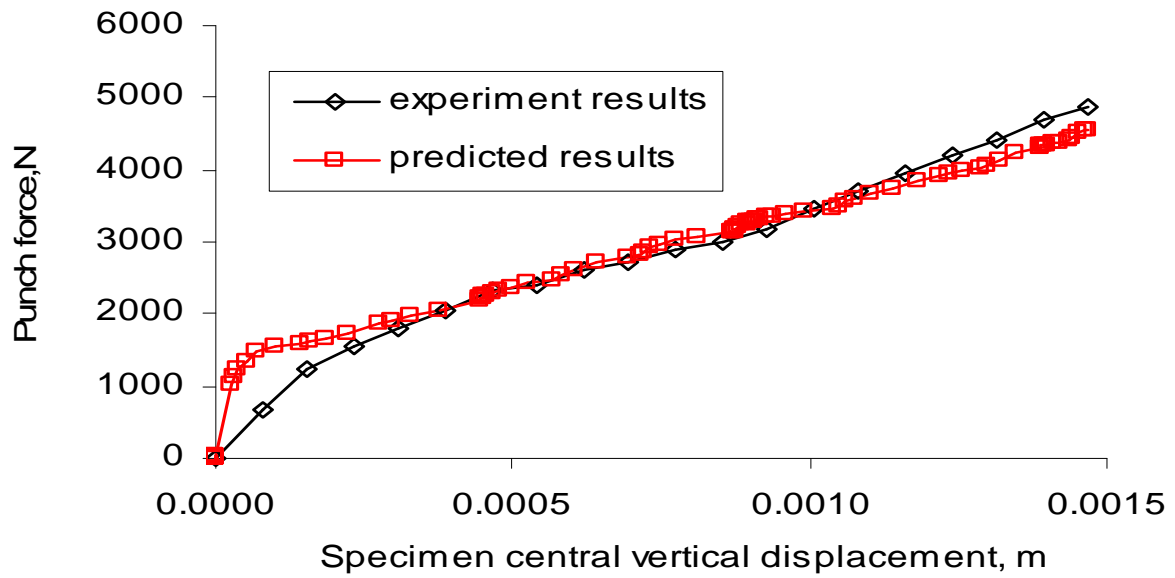


The values of objective function for each chromosome

The best values obtained for n and α are 9.375 and 0.932 respectively



The predicted Stress strain curve



Comparison between the experimental and predicted results

Conclusions

1. A novel plane strain SPT tools for material plastic properties characterization have been successfully designed, assembled and tested.
2. The procedure of genetic algorithm was set up to characterize the material's plastic parameters (Ramberg-Osgood constitutive relationship).
3. The predicted material's yield stress and UTS are reasonable within the expected range.

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Future work

1. To make the procedure to be executed automatically by using Abaqus python scripts
2. Will be extended to material's plastic damage and creep parameters characterization.