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IDENTIFICATION OF MULTILAYER MATERIAL PROPERTIES BASED ON THE APPLICATION OF AN INVERSE ANALYSIS TECHNIQUE

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INTRODUCTION:

- Nanoscale multilayers are attractive because of the amplification of the hardness as the layer thicknesses are decreased to the nanometre range. The most common systems include metal/metal and metal/ceramic multilayers which are capable of achieving high strength, high toughness, and damage tolerance [1]. It is also being used for microelectromechanical systems (MEMS) devices. However, prediction of their mechanical behaviour is not straight-forward. A lot of parameters have to be considered when designing multilayer component system and it is generally difficult to obtain the material properties of each layer. Typical tensile testing is not useful for such systems and nanoindentation will only give partial information about the materials such as its hardness and elastic modulus.

OBJECTIVES:

- The aim of this study is to develop a robust technique that can extract the material properties from such systems.
- The identification of the individual layer properties can then be utilised into different mechanical configuration to assess the behaviour of the composite.

METHOD:

- The model considered in this study consists of 1 μm thick alternate layers of materials A and B. Conical indenters tips with 70.3° (semi) opening angle are assumed to simulate pyramidal indenters [2]. The indenters are assumed to be perfectly sharp and rigid. Fig. 1 shows a sample deformed FE model adopted.
- The mechanical behaviour of the materials is assumed to obey the Hencky-Huber-Mises (HHM) model. Thus, they are characterised by the three parameters E, ν and σ_0, representing the modulus of elasticity, the Poisson's ratio and the uniaxial yield stress respectively.
- Indentation depths of 0.2 μm and 0.8 μm were simulated to assess their responses and determine if the sequential indentation of the two will be beneficial for the approximation of the materials properties.
- In order to enhance computation time and avoid relying on finite element simulation, a quick and equally sensitive approach was employed to assess the proposed method [3] through numerical verification.

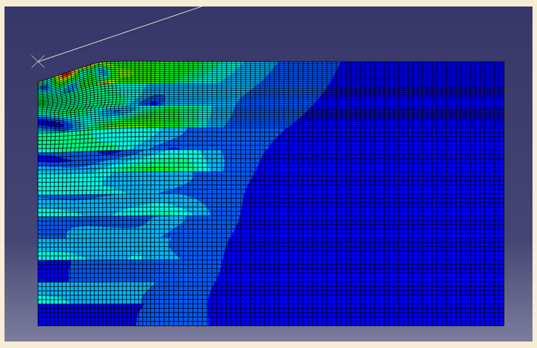


Fig. 1. 2D axis-symmetrical 12 layers finite element model

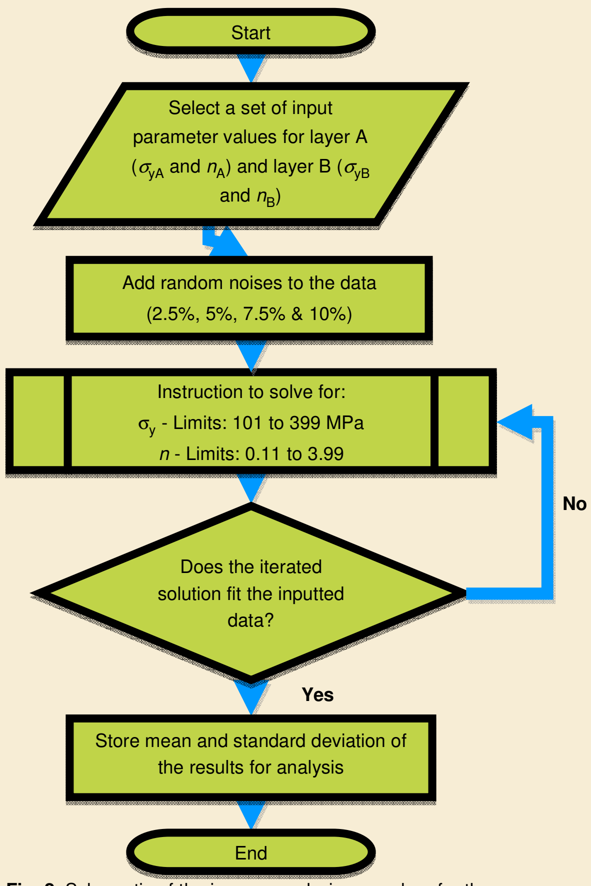


Fig. 2. Schematic of the inverse analysis procedure for the multilayer system

PSEUDO-EXPERIMENTAL DATA ANALYSIS:

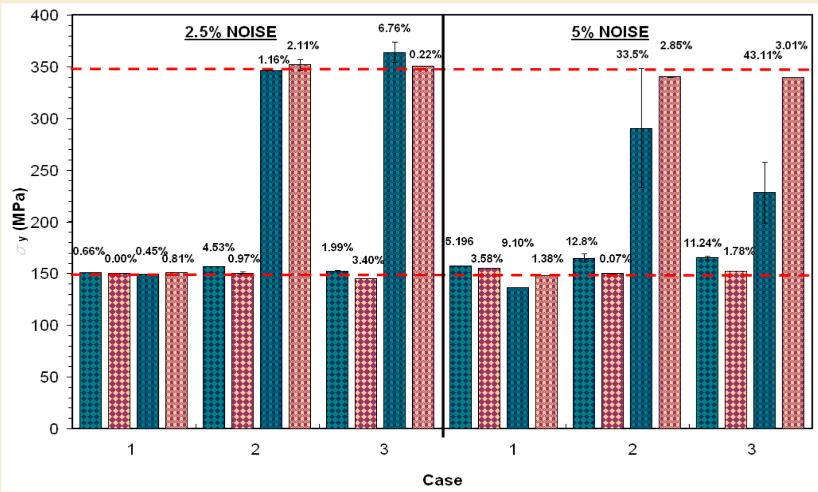
- A range of multilayers having different material properties were simulated using forward finite element simulations. Random noises of 2.5% to 10% were added to the indentation curve and imprint obtained to test the robustness of our inverse analysis method. The material properties ranged from 100 MPa to 400 MPa for the yield stresses and 0.1 to 0.4 for the strain hardening exponent.
- Substitution of the finite element was achieved by compiling a database of forward finite element simulation output data with respect to different material properties. Then, each iteration computes the results based on the following relationship:

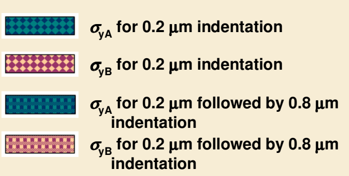
$$N_i(\varsigma) \equiv \frac{(\xi-\xi_i)\cdot\ldots\cdot(\xi-\xi_{i-1})\cdot(\xi-\xi_{i+1})\cdot\ldots\cdot(\xi-\xi_n)}{(\xi_i-\xi_1)\cdot\ldots\cdot(\xi_i-\xi_{i-1})\cdot(\xi_i-\xi_{i+1})\cdot\ldots\cdot(\xi_i-\xi_n)}\ ; \quad f(\xi) \approx u(\xi) = \sum_{i=1}^{n} N_i(\varsigma)\cdot u_i \quad \text{where: } N_i(\varsigma_j) = \delta_{ij} \quad \text{and} \quad u_i = f(\xi_i)$$

ξ_i = Parameter value for any of the 4 parameters
$N_i(\varsigma_j)$ = Total weighted parameter
u_i = Matrix of indentation reaction and imprint stored from direct analyses
$f(\xi)$ = Matrix of indentation reaction or imprint computed

RESULTS & DISCUSSION:

- Several aspects were considered to investigate the method. The factors are: (i) the influence and/ or benefit of utilising the imprint in the analysis; (ii) weights factored to the differences to help the estimation; (iii) the advantage of using sequentially two indentation depths; and (iv) how accurate the estimate were compared to the true parameter values for the different level of added noises.
- To ensure robustness, convergence were evaluated for 25 random noises for each case. The results are presented in Fig. 3, in which the crosses show the true value. The two indentations depths were applied in this case.
- Several cases were considered with different combination of parameter values. Overall, the estimates were consistent as shown in Fig. 4. The maximum error is 6.76% for the 2.5 added noise and a bad approximation of 43% for the 5% added noise.





Case	σ_{yA} (MPa)	n_A	σ_{yB} (MPa)	n_B
1	150	0.15	150	0.15
2	150	0.15	350	0.15
3	150	0.15	350	0.35

Fig. 4. Approximation results from the inverse analyses for 2.5% and 5% added noises

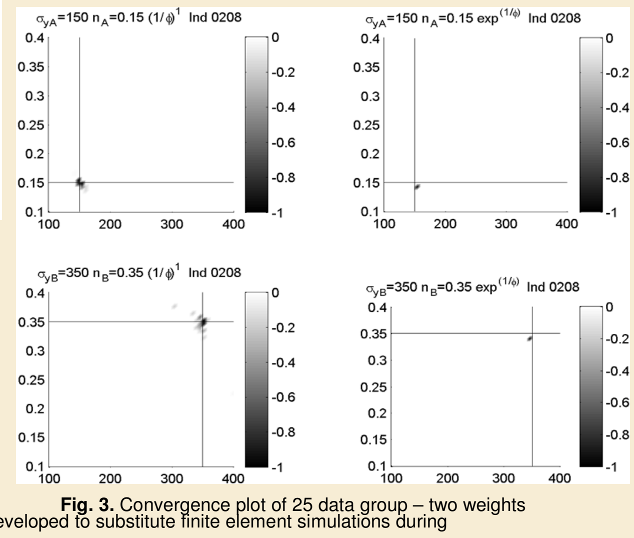


Fig. 3. Convergence plot of 25 data group – two weights

CONCLUSIONS:

- We have successfully proven that the technique can estimate the material properties of multilayer materials system with reasonable accuracy. The method developed to substitute finite element simulations during iteration is particularly useful by considerably reducing computation time. It was also found that there is an improvement in the estimation when the sequential indentation depths of 0.2 μm and 0.8 μm were utilised. In summary, the method works reasonably well provided good data are available and it is always good practice to perform a sample set of 20-25 data records to ensure representation of the true material properties.

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