A Preliminary Numerical Stress Analysis of a Dynamic Biaxial Testing Machine

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Summary.

The paper concerns a set of 2D and 3D stress analysis carried out by ADINA code on a cruciform specimen under static and dynamic loads. The specimen is devoted to investigate material dynamic constitutive equation by biaxial loading devices. The stress distribution resulted constant in the central area of the specimen (constant thickness), while some stress concentrations resulted in external branch elements.
1 - Introduction.

In fast breeder reactor safety analysis, structural materials behaviour at high strain rates must be known. The development of generalized constitutive equations for materials requires additional experimental data.

Different devices have been constructed covering different strain rate ranges, (up to $10^3$ sec$^{-1}$) and different specimen sizes $[1]$, $[2]$. At J.R.C. Ispra Establishment one of the biaxial dynamic machines allows tension and compression loadings on cruciform specimens.

The stress, strain and strain rate diagram under biaxial loading is obtained by loading the four arms of a cruciform specimen (Fig. 1), simultaneously, up to rupture, along two orthogonal axes.

This work is devoted to investigate theoretically the stresses and strains fields in the biaxial specimen.

A proper design of the specimen must assure an uniform stress distribution inside the material to be investigated while the constitutive law is supposed to be known.

In this respect the shape of the connections linking the test specimen and the four arms is very important.

The finite element ADINA code [3] was considered to be the most suitable tool for investigating the non linear specimen response as well as under static and/or dynamic conditions.

A preliminary 2 D analysis was devoted to evaluate this specimen response under external static conditions, using at first the plane stress assumption.

Then it has been studied the dynamic non linear response of the sample under the previous assumptions i.e. 2 D analysis and plain stress hypothesis.

Finally investigations have been performed on a 3 D specimen model under external static conditions 2 - 2 D static analysis.

Fig. 2 shows the finite element network simulating 1/4 of the specimen (n° 189 elements with 650 nodes) used for 2 D analysis (plane stress assumption).

Elasto-plastic analysis was carried out on two $G(x)$ curves that have been obtained from AISI-316 L experimental dynamic behaviour (the strain rates varying from 0,2 . 10$^{-2}$ sec$^{-1}$ to 44 sec$^{-1}$).

The first curve had a yield stress $G_{y1} = 400$ N/mm$^2$ and a tangential modulus $E_{t1} = 600$ N/mm$^2$, while the second curve had $G_{y2} = 500$ N/mm$^2$ and $E_{t2} = 1500$ N/mm$^2$; in both cases the Young modulus has been assumed to be $E = 2,1 . 10^5$ N/mm$^2$. 

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Loads up to 20,000 Newton on each arm have been considered. Because of the plastic strains, a step by step loading process has to be introduced.

Fig. 3 and 4 show $\sigma_y$-stress and equivalent stress behaviour v.s. load in two typical regions i.e. in the specimen centre (element N° 1) and at specimen border (element N° 145).

Incipient plastic strains are found at the border at about 7000 N load level for material 1, and at about 8700 N load for material 2. In the specimen centre plasticity occurs for the first time when the 9000 N load and 11,500 N load levels are respectively reached using materials curve 1 and 2.

All central area reached simultaneously plastic state with an uniform stress distribution.

Table 1 gives for material n° 2 stresses along section A of Fig. 2.

In central area of test specimen, Mohr circle reduces to a point, while in proximity of borders (like in elements n° 145, n° 146) shearing stress $\sigma_{yx}$ is of the same order of magnitude of normal stresses ($\sigma_x; \sigma_y$).

3 - 3 D static analysis.

A very detailed 3 D specimen was constructed by 3 D elements of different shapes. The specimen material was AISI-316 L at 44 sec$^{-1}$ strain rate.

Fig. 5 shows $\frac{1}{8}$ of test specimen model; fig. 6 and fig. 7 show the three layers discretization of the model.

The comparison between the 2 D and 3 D analysis allows us to underline the following conclusions: the central area of test specimen, where thickness is constant, always remains in a 2 D stress state validating the plane stress assumptions. Differences between 2 D and 3 D results are very small, and stresses perpendicular to specimen are negligible.

Outside central area, $\sigma_z$ reaches in some elements values of the same order of magnitude of $\sigma_y$ and $\sigma_x$.

The increasing in $\sigma_z$ and shear stresses outside central area of specimen means that outside the central area, 2 D analysis gives a rough approximation, while it is suitable for stress analysis in the region of small and constant thickness.

Tab. 2 and Tab. 3 give stress values along two sections of the specimen (see fig. 5, 6).

4 - Dynamic analysis.

Dynamic stress analysis has been carried out with different models. In first step only central test specimen at constant thickness 1.5 mm., without branch elements has been considered (2 D analysis).
Fig. 8 shows 1/8 of model with 15 plane elements and 56 nodal points.

Dynamic loads with maximum value of 15,000 N on each arm have been considered.

Fig. 9 gives the behaviour of equivalent stress v.s. time in two regions of test specimen, assuming elastic material properties \((E = 2.1 \times 10^5 \, \text{N/mm}^2)\) for AISI 316 L.

Fig. 10 gives the behaviour of equivalent stress v.s. time in two regions of test specimen, assuming elasto-plastic properties \((\sigma_y = 500 \, \text{N/mm}^2; \, E_t = 1500 \, \text{N/mm}^2)\).

Fig. 11 gives a comparison of the y-displacement of point A obtained respectively under static and dynamic load.

This preliminary dynamic analysis shows that the equivalent stress for elastic material closely reproduces the external dynamic load behaviour, while for elasto-plastic materials large stresses oscillations follow the load ramp.

The dynamic load increases considerably the maximum displacement in comparison with static load.

Future work shall be devoted to investigate the dynamic response of the complete biaxial system i.e. specimen with branch elements and four loading arms.

References


/ 2 / HAYASHI, T., TANIMOTO, N., "Behaviour of material under dynamic combined stresses of torsion and tension", Faculty of Engineering Science, Osaka University, Toyonaka, Osaka, Japan.

Fig. 3 - Behaviour of $\sigma$ vs. load in two typical regions of specimen

Fig. 4 - Behaviour of equivalent stress in two typical regions of specimen

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Fig. 5 - 3D Model

Fig. 6 - 3D Model layers

Fig. 7 - Element number in each layer of 3D Model

Fig. 8 - 2D Model for dynamic analysis
Fig. 9 - Equivalent stress (Gauss point N.3 in elements N.2 and N.11)

Fig. 10 - Equivalent stress (Gauss point N.3 in elements N.2 and N.11)

Fig. 11 - Y displacement of point A (see fig. 8)