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► To cite this version:

P. Church, J. Macmahon. A Comparison of 3D Simulations Against Experiments for the Torsion Test. Journal de Physique IV Proceedings, 1997, 07 (C3), pp.C3-747-C3-752. 10.1051/jp4:19973127 . jpa-00255413

HAL Id: jpa-00255413

<https://hal.science/jpa-00255413>

Submitted on 1 Jan 1997

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A Comparison of 3D Simulations Against Experiments for the Torsion Test

P. Church and J. Macmahon

Defence Evaluation Research Agency Fort Halstead, Sevenoaks, Kent TN14 7BP, U.K.

Abstract

This paper describes simulation studies using the public domain version of the **DYNA3D** hydrocode of the torsion test, which by definition is a 3 dimensional test. The mesh resolution required to resolve the stress system and the general shear deformation within the gauge length of the specimen has been investigated. Furthermore the simulations have been compared in detail with experiments in terms of the shear stress/strain curve and the general strain distribution over the gauge length under conditions of steady deformation for iron and RHA. Once the numerical technique has been proven then aspects of localisation and instability can be more thoroughly investigated under a well characterised loading scenario.

1.INTRODUCTION

The simulation of many ballistic events rely on accurate constitutive relations which are applicable under tensile, compressive and shear loading regimes at high strain rates and high strains. Many of these ballistic processes, such as shear plugging, are caused by shear localisation resulting from adiabatic shear phenomena. Thus the simulations must be capable of resolving this localisation behaviour in order to predict the shear plugging. Furthermore recent studies [1] have shown that the work hardening behaviour of iron and RHA is significantly less in torsion than in tension or compression. Indeed for a variety of RHAs tested the work hardening is almost zero. This behaviour should therefore be taken into account in the constitutive model.

Since a ballistic event is a very complex process involving many mechanisms, it is useful to simulate a test which isolates the shear localisation to allow an in-depth evaluation of constitutive models and approaches. Such a test is the torsion test in which a specimen is deformed in pure shear, where shear localisation and instability in the form of adiabatic shear can be reproduced.

This paper describes the development of a full 3D simulation capability of the torsion test using the public domain version of the lagrangian hydrocode **DYNA3D** [2] and preliminary comparison with torsion test experiments performed at Oxford University.

2.DESCRPTION OF TORSION TEST

The torsion test performed at Oxford University consists of a thin walled specimen which is held fixed at one end and twisted at the other using a torsional Hopkinson bar, such that the gauge length of the specimen is under a state of pure shear. The specimen geometry is illustrated in **Fig 1** and a full description of the apparatus is given in [3]. The measurements produced for comparison with the simulations are the dynamic shear stress/shear strain in the specimen gauge length. In addition high speed cameras are being used to monitor a deforming grid etched onto the specimen gauge length compare directly with experiments. Future work will attempt to produce and film shear instability in the specimen due to localisation using high speed cameras.

Fig 1 Section Through Specimen

3.NUMERICAL RESULTS

The simulation studies have been performed using the lagrangian hydrocode **DYNA3D**. Although the specimen does have symmetry the rotational velocity must be applied through these symmetry planes, thus a full 3D analysis is required. The loading on the specimen in the experiment is transmitted via a confining collar which is also included in the simulation. The design of the mesh has been constructed to allow the maximum number of elements along the gauge length. The loading on the specimen in the simulation is imparted via a rotational velocity load curve applied to the confining collar, calculated such that the strain rate in the specimen gauge length is comparable with the experiment at around $2000s^{-1}$. A typical 3D mesh of the specimen showing the gauge length is illustrated in **Figs 2 & 3**.

Fig 2 3D View of Numerical Mesh

Fig 3 Cross sectional view of Numerical Mesh

The simulations were designed to investigate the effect of mesh resolution on the stress system within the specimen gauge length as well as the dynamic shear stress/shear strain curve as compared with the experiment.

The comparison with the experimental stress/strain curves were performed for REMKO AQ85 iron and a UK RHA with nominal hardness of about 300Hv. The constitutive models used for each material were based on the generic model for steel [4]. The constitutive equation is given below with constants for the iron and RHA.

$$\sigma = (C_1 + C_5 \varepsilon^n) \mu_t / \mu_{293} + C_2 \exp(-C_3 T + C_4 T \log \varepsilon d)$$

Where σ = effective stress

T = temperature

ε = effective plastic strain

εd = strain rate

The relative constants are:

Iron	C1=50MPa	RHA	C1=710MPa
	C2=1130MPa		C2=575MPa
	C3=0.00515		C3=0.0048
	C4=0.000262		C4=0.00032
	C5=357MPa		C5=567MPa
	n=0.52		n=0.41

3.1 Mesh resolution study

The specimen geometry is such that the gauge length is only a few millimetres long and the thickness of the gauge tube is only 0.25mm. This coupled with the fact that the whole specimen must be simulated in 3D implies that a large number of elements are required to describe the full geometry. However, the deformation and localisation processes take place solely within the gauge length where it is assumed that the shear stress and shear strain through the gauge length length thickness are uniform.

Two mesh resolutions were used in the simulations to investigate the nature of the stress system in the gauge length. The 'coarse' mesh comprised 34000 elements in total with 32 along the gauge length and 4 through the gauge length thickness. The 'fine' mesh comprised 82000 elements with 64 along the gauge length and 6 through the gauge length thickness. Whilst these meshes are relatively modest in terms of the resolution in the gauge length the simulations were taking around 10 hours on the CRAY YMP.

The general stress systems for the coarse mesh simulations are illustrated in **Figs 4a** and **4b** respectively. Closer inspection of the element histories show that the average shear stresses and strains on the inner surface of the gauge length are more or less the same as those on the outer surface at the same time for both the coarse and fine mesh simulations. Thus it can be concluded that the mesh resolution of 4 elements through the gauge length thickness is sufficient to properly resolve the prevailing stress system. However, there are some differences in the shear stresses along the gauge length. Due to the significant run time on the supercomputer, there will always be a compromise between the accuracy and the run time. Future work will investigate the use of a finer mesh resolution along the gauge length. Clearly this has implications when simulating the details of shear localisation within the gauge length.

Fig 4a Fringes of Maximum Shear Stress, 100 us. Fig 4b Fringes of Maximum Shear Stress, 200 us

4.0 COMPARISON WITH EXPERIMENT

One of the key measurements obtained experimentally is the dynamic shear stress/shear strain curve. The simulation for the REMKO AQ85 iron has been run to plastic strains of 0.5 using the modified Armstrong-zerilli model given previously. The comparison with the experiment is shown in **Fig 5a**, which shows reasonable agreement with the experiment except that the simulation show the stress increasing with strain to a level of 350mpa compared with the flat experimental curve at about 300MPa. If the work-hardening coefficient C5 is set to zero then the comparison is in much better experimental agreement in terms of the maximum stress level **Fig 5a**. However, the predicted curve shows a slight degradation with strain, due to thermal softening whereas the experimental curve is almost flat. The reason for this is

probably due to the work-hardening coefficient C5 being set to zero, whereas in reality, although the work-hardening rate is less in torsion than under uniaxial conditions, it still has a finite value. This will be determined from future experimental tests and incorporated into the models.

Using the constants for RHA, where the work hardening is assumed to be zero in shear (i.e C5=0 in shear), the comparison is shown in **Fig 5b**. Again, the same trend is observed with the RHA, that was seen with the AQ85. It is evident that a small but finite torsional work hardening rate will be needed, to match the experimental data accurately.

These simulations have not been progressed to the onset of localisation and failure or adiabatic shear, which will be the subject of a future study

5.0 GENERAL DISCUSSION

The simulations are still at a preliminary stage and a more thorough investigation of the effect of the mesh resolution along the gauge length, on the detailed stress system and localisation behaviour of the material, is required. However, the simulations have already yielded an invaluable insight into the experimental torsion test set-up and the general deformation behaviour of the material as well as the sensitivity to subtleties in the constitutive model.

To further advance these techniques to make a significant contribution to the study of shear instability it is essential that the mesh resolution along the gauge length is increased substantially. This is particularly important when the constitutive relations incorporate a temperature term and the localisation and adiabatic shear behaviour of the material is strongly influenced by its thermal behaviour. In addition this will be important when the predicted strains are compared with the strains from the etched grid on the specimen.

This study has performed some useful ground work in simulating the complexities of the torsion test in 3D which can be used as a springboard for more detailed investigations. In particular the simulations have shown that the test can be described without the need to include full details of the Hopkinson bar test equipment within the analysis, which would render the study completely impractical. This has been possible due to the simulations being capable of accurately describing the boundary conditions on the specimen.

6.0 CONCLUSIONS AND RECOMMENDATIONS

1. A technique using the **DYNA3D** hydrocode has been established to simulate the torsion test in full 3D geometry.
2. The simulations are in reasonable agreement with the experiments in terms of the predicted dynamic shear stress/shear strain curves using the modified Armstrong-zerilli model for REMKO AQ85 iron and RHA. The models require modification to account for the precise work-hardening in torsion.
3. The current mesh resolution along the gauge length are probably insufficient to accurately resolve the localisation behaviour of the specimen materials. This is necessary to investigate detailed instability mechanisms.

References

- [1] International European Programme Group, Panel III, 'Phase II Report', 1990
- [2] DYNA3D, a non-linear, explicit, Three Dimensional Finite Element Code for Solid and Structural Mechanics. Lawrence Livermore National Labs. 1996.
- [3] J Harding & J P Noble, 'Modifications to the Torsional Split Hopkinson-Bar Apparatus, Fourth Interim Report', University of Oxford, April 1995.
- [4] B.D. Goldthorpe et al. , ' A wide range constitutive equation for medium and high strength steel', Journal De Physique IV, Vol 4, Sept 1994.