# PhD in Systems, Energy, Computer and Telecommunications Engineering

## XXX Cycle – 3rd Year

**PhD Student: Raffaele Barbagallo**
**Tutor: Prof. Giuseppe Mirone**

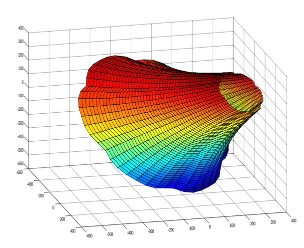
Department of Electric, Electronics and Computer Engineering, University of Catania, Viale Andrea Doria 6 95125 Catania, Italy, e-mail: rbarbaga@dii.unict.it

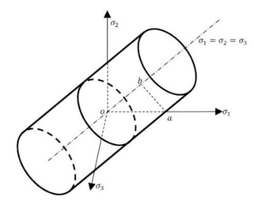
# CHARACTERIZATION AND MODELLING OF METALS

## STATIC

### INTRODUCTION

The elastoplastic characterization consists of the determination, by way of experimental tests, of the hardening curve of the material. Modern materials are very ductile so they can be subjected to large deformations before failure; this is very helpful in the manufacturing design of many components involving, for example, forming processes. These kind of processes are often simulated with *FEM* analysis but, without a correct representation of the material plastic behaviour and failure, this tool is inefficient. In this field, a new yield model based on all the stress invariants and a novel experimental characterization method have been developed.





### RESEARCH ACTIVITIES

- **New Yield Model**

The new yield model proposed here is able to take into account not only the second invariant of stress, typically used in the classic approach, but also the effect of the others two invariants. The mathematical formulation of the new yield function is the following:

$$\sigma_{Eq}(\vartheta)=\sigma_{TE}\cdot\left(\cos\left(\frac{\pi}{6}\right)-m\cdot\sin\left(\frac{\pi}{6}\right)\right)\cdot\frac{\sqrt{1+\tan^2(\vartheta)}}{1-m\cdot\tan(\vartheta)}\cdot\left[1+qa\cdot\frac{\left(\vartheta^2-\pi/6\cdot\vartheta\right)}{\vartheta*^2-\pi/6\cdot\vartheta*}\right] \qquad m=\frac{\sigma_{TE}\cdot\cos(\pi/6)-\sigma_{SH}}{\sigma_{TE}\cdot\sin(\pi/6)}$$

where $\sigma_{TE}$ is the reference tensile hardening function of the material, $\sigma_{SH}$ is the reference torsion hardening function of the material, $\theta$ is the Lode Angle, $\theta*$ is the Lode Angle of a reference test and $qa$ is the parameter of the model to be tuned as a function of the material. The new model was implemented in a *Fortran* script to be run within the *FEM* software *Marc*® and it was checked against literature experimental data on Ti6Al4V by Allahverdizadeh, Nima, et al. (2015) [1]. The above experimental campaign includes pure tension, pure torsion and mixed tension-torsion tests. In *Figure 1*, the experimental results are compared to the predictions of the proposed yield criteria (plots A and C) and to the outcome of finite elements with standard Mises plasticity (plots B and D) showing the effectiveness of the new model.

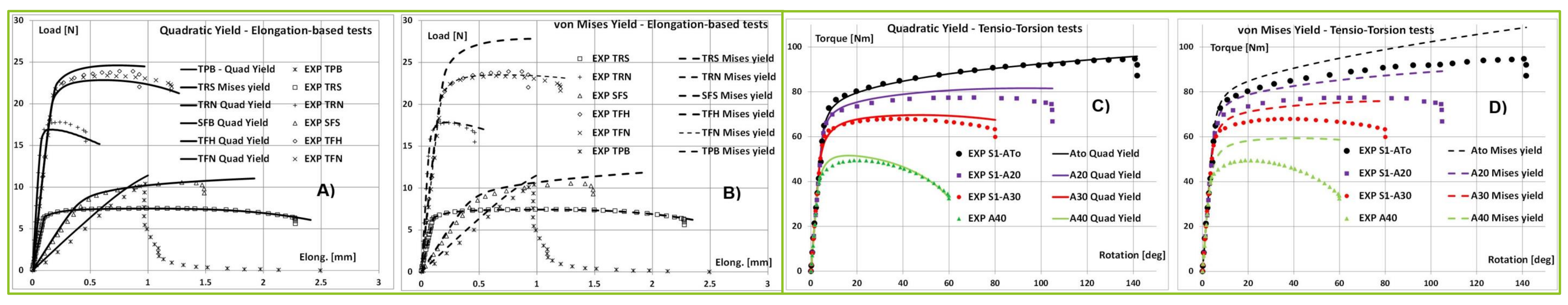


*Figure 1: FEM by new model yield and by von Mises yield compared to the experimental data*

- **Novel Experimental Characterization Method**

In collaboration with the research group of Prof. Verleysen of Ghent University, a new methodology was developed for translating the engineering curves, coming from tensile tests, into the more accurate true curves via material-independent mathematical tools named *MVB* functions, which only depend on the necking initiation strain and on the aspect ratio of the undeformed cross section. To obtain such procedure, several *FEM* simulations were made of the tensile tests for the investigated cross sections. The new procedure was successfully validated for an aluminium alloy thin rectangular specimen, a carbon steel round specimen and a mild steel thick rectangular specimen. In *Figure 2* are shown the procedure for obtaining the *MVB* and the applications results.

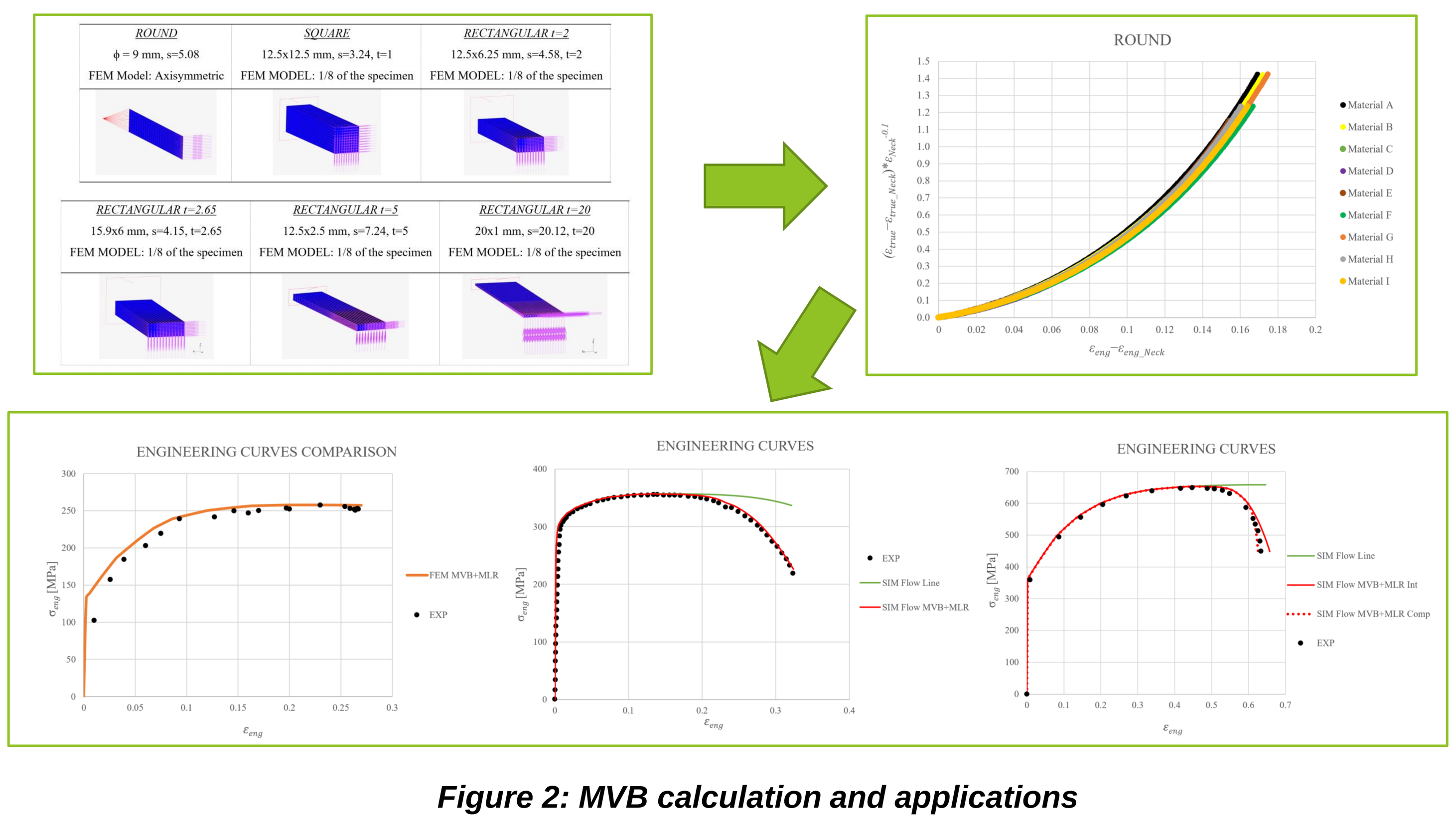


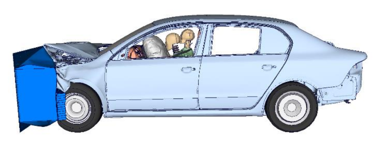
*Figure 2: MVB calculation and applications*

[1] Allahverdizadeh et al. "An experimental and numerical study for the damage characterization of a Ti–6AL–4V titanium alloy." International Journal of Mechanical Sciences (2015): 32-47

## DYNAMIC

### INTRODUCTION

The strain rate has a wide range of effects on critical material properties and there are many applications where materials are expected to perform under high strain rate conditions. In this field, the approximations of the classic Engineering Approach compared with the True Approach made possible by a fast camera and the necking induced freezing of the strain rate effect have been studied.



### RESEARCH ACTIVITIES

- **Experimental Issues in SHTB tests and necking induced freezing of the strain rate effect**

Fast Camera recording is crucial in a SHTB tests because it is the only way to monitor the variation of the diameter of the specimen during the test and to obtain the true curve of the material, the only one able to completely characterize its behaviour.

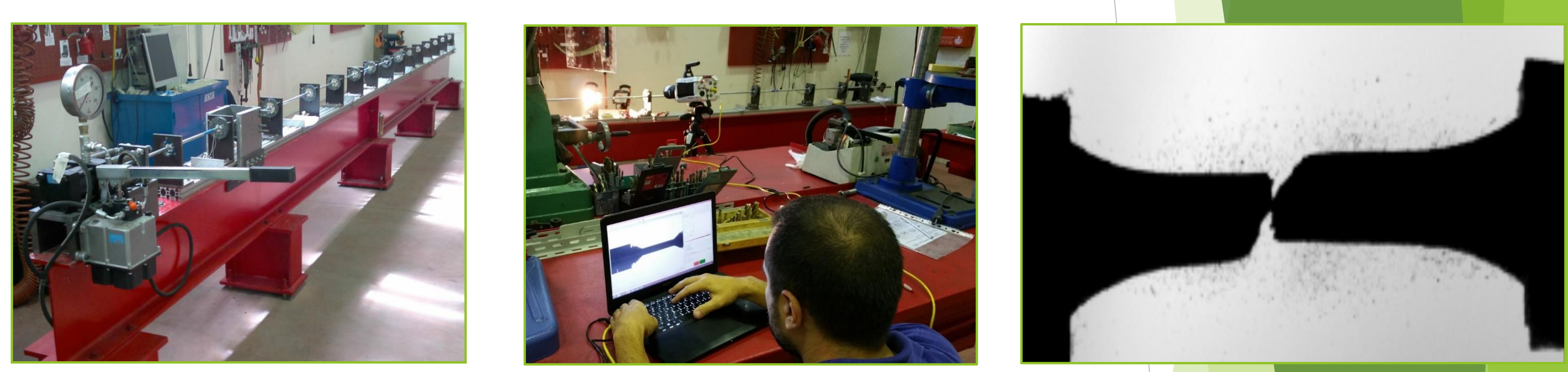


*Figure 3: Classic SHTB setup and upgraded setup with the fast camera*

To prove this, the usual procedures for tensile tests with the Split Hopkinson Tension Bar (SHTB) and for the successive calculation of the relevant material variables were analysed, in order to estimate the possible approximations. The effects of the specimen length/diameter ratio and that of the necking on the dynamic hardening were investigated by experiments, according to the classical SHTB procedures and to the more advanced camera assisted technique. The engineering variables (stress, strain and strain rate), based on strain gauges readings along the bars, were compared to the corresponding true variables, only achievable by high speed camera–assisted tests and successive optical measurements of the evolving diameter of the specimen.

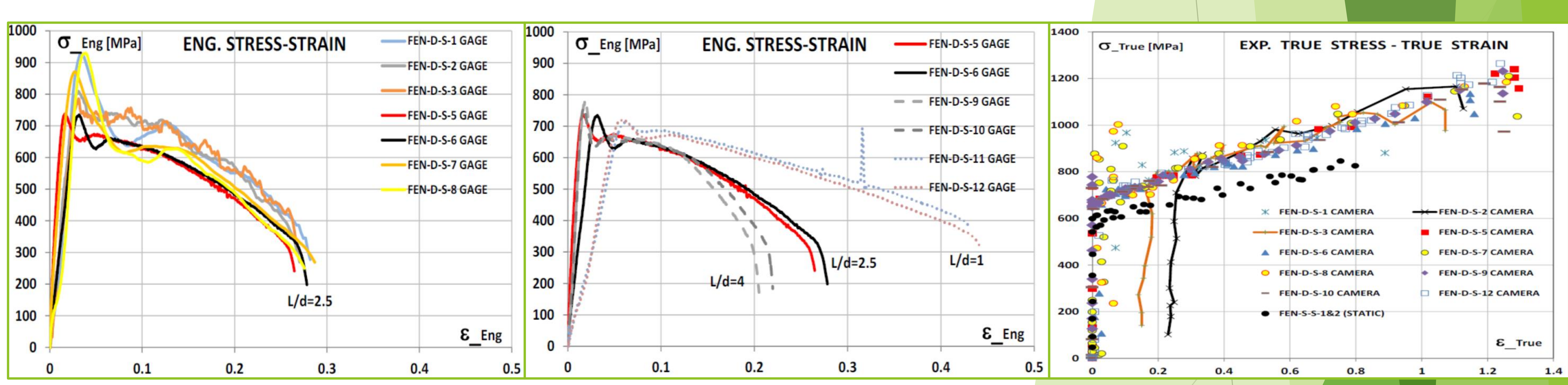



*Figure 4: Engineering and True Curves of the FEN specimens*

Comparing the engineering curves obtained with the classic approach with the true curves obtained thanks to the fast camera acquisition for FEN steel specimens (*Figure 4*), it is possible to see that the specimen slenderness greatly influences the engineering variables while not affecting at all the true variables; the comparison also gives a quantitative estimation of how much the effective values of stress and strain are underestimated by the engineering approach. The conclusion from the above considerations is that fully "true" experimental data based on fast camera acquisitions and optical measurements of the specimen diameter are essential for delivering good experimental accuracy in the dynamic characterization. Finally, the necking onset was demonstrated to freeze the sensitivity of the stress-strain curve to the strain rate; this feature, supported by both experiments and finite elements analyses, might have a considerable impact on the whole dynamic characterization by means of SHTB of ductile metals undergoing large post necking strains before failure.

### Related Papers and Mobility

- Mirone, G., Corallo, D., & Barbagallo, R. (2017). Experimental issues in tensile Hopkinson bar testing and a model of dynamic hardening. *International Journal of Impact Engineering*, 103, 180-194.
- Mirone, G., Barbagallo, R., & Cadoni, E. (2017). Tensile Test of a HSLA Steel at High Strain Rates with Two Different SHTB Facilities. *Procedia Engineering*, 197, 89-98
- Mirone, G., & Barbagallo, R. (2017). Congelamento dello Strain Rate Effect In Prove Dinamiche su Hopkinson Bar. *Proceedinigs of the 46th AIAS National Conference*, Pisa, 2017
- Mirone, G., Verleysen P. & Barbagallo, R. (2017). Legame tra Misure Macroscopiche in Prove di Trazione e Variabili di Hardening su Scala Semi-Locale per la Caratterizzazione dei Metalli. *46th AIAS National Conference*, Pisa, 2017
- Mirone, G., Barbagallo, R., Corallo, D., & Di Bella, S. (2016). Static and dynamic response of titanium alloy produced by electron beam melting. *Procedia Structural Integrity*, 2, 2355-2366.
- Mirone, G., Barbagallo, R., & Corallo, D. (2016). A new yield criteria including the effect of lode angle and stress triaxiality. *Procedia Structural Integrity*, 2, 3684-3696.
- Mirone, G., Corallo, D., & Barbagallo, R. (2016). Interaction of strain rate and necking on the stress-strain response of uniaxial tension tests by Hopkinson bar. *Procedia Structural Integrity*, 2, 974-985.
- Mirone, G., Corallo, D., & Barbagallo, R. (2016). Effetto del necking sulla amplificazione dinamica dell'hardening in prove ad alti strain rates. *Proceedinigs of the 45th AIAS National Conference*, Trieste, 2016.
- Mirone, G., Barbagallo, R., & Corallo, D. (2016). Un nuovo criterio di snervamento con dipendenza dall'angolo di lode e dalla triassialità. *Proceedinigs of the 45th AIAS National Conference*, Trieste, 2016.

➢ ***Three months at the University of Ghent, Belgium, working in the research group of Prof. Verleysen on plasticity of metals***.