A new tensile test sample geometry for oscillation-free determination of material properties at high strain rate

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ABSTRACT- The determination of plastic deformation properties of materials under high speed loading has been a challenge for many years. Structural vibrations or the system ringing in a conventional servo-hydraulic tensile testing machine deteriorates the quality of force measurement [1,2], which makes a precise determination of the plasticity of materials very difficult, especially in the case of determination of yield locus, strain hardening and fracture strain.

In this work, at first, the system ringing effect of the entire hydraulic tensile testing system incl. machine frame, hydraulic jack, sliding bar, acceleration grip, sample, sample clamping, load cell etc. were analyzed by using FE analysis [3]. The FEM was verified firstly by simple bar models for which the analytical physical solutions are available based on the fundamental bar theory for stress waves [4]. For the analysis, only the center part of the testing system, which contains the sliding bar, acceleration grip, sample, sample clamping and load cell are required. The machine frame and plate are not essential. The results were that the ringing of the system is strongly location and geometry dependent: the force oscillations are very strong in the upper part of the center system (hydraulic jack, sliding bar) and high in the load cell area but small in the sample plastic deformation zone.

Inspired by the principle of the split Hopkinson bar (SHB) [4, 5] and based on the above mentioned FE-analysis, a new type of tensile sample has been developed and verified. As can be seen in figure 1, besides the usual major plastic deformation area 3, the new sample has an additional area 5, which is only elastically deformed. Within this area, there is an additional weakening area 6. By satisfying certain mechanical and geometrical condition a very small secondary minor plastic deformation may take place and the rest of the elastic deformation zone show a homogeneous elastic strain field (figure 2). The determination of the sample geometry has been done by FEM. They are independent of steel grade and aluminum grade, at least at the investigated range of materials from mild steel to ultra-high-strength carbon steels and 5xxx to 6xxx aluminum. The force oscillation in this elastic zone 5 is nearly zero and the zone can be large enough. Therefore, the deformation forces can be measured by strain gauge without any ringing effect.

There are two possible theories to explain this phenomenon. One is based on the mechanical and the other one on physical analysis. Both of them will be introduced in this work shortly.

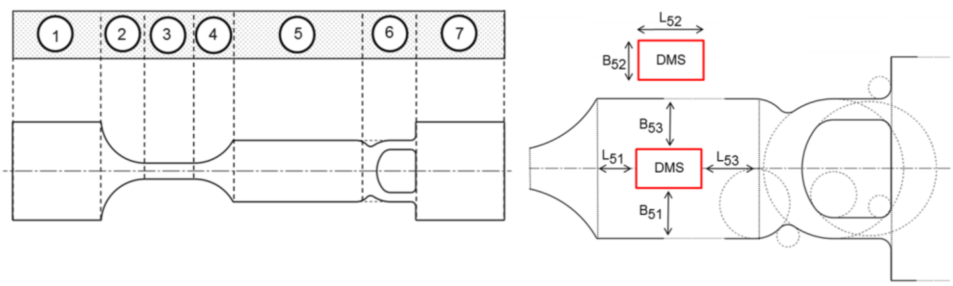

Figure 1: A new sample geometry for ringing-free force measurement in DMS-area

In addition, the plastic deformation behavior of steels and Aluminum were determined and analyzed by using this new type of specimen for a wide range of strain rate of 10^{-4} - 10^{3} /s. Figure 3 shows the stress-strain curves of an advanced high strength DP 600 steel at different strain rates. The data there are all directly measured data without any filtering. The strain rate sensitivity of yield and tensile strength can be determined clearly. The influence of strain rate and stress triaxiality on the yield locus and its hardening behavior are also determined.

Since the real strain rate on the sample changes during the test because of the local necking of the tensile

sample, an algorithm is proposed to obtain a stress-strain curve at constant strain rate. These are the essential data for the modeling of materials in vehicle crash simulation.
In the future, the same principle will be applied to tensile test samples with different stress triaxialities and lode angles. The strain rate dependence of yield locus, failure strain and hardening behaviors of metallic materials can be measured by using the sample geometry and method which avoid artificial effects of changing measuring technique.

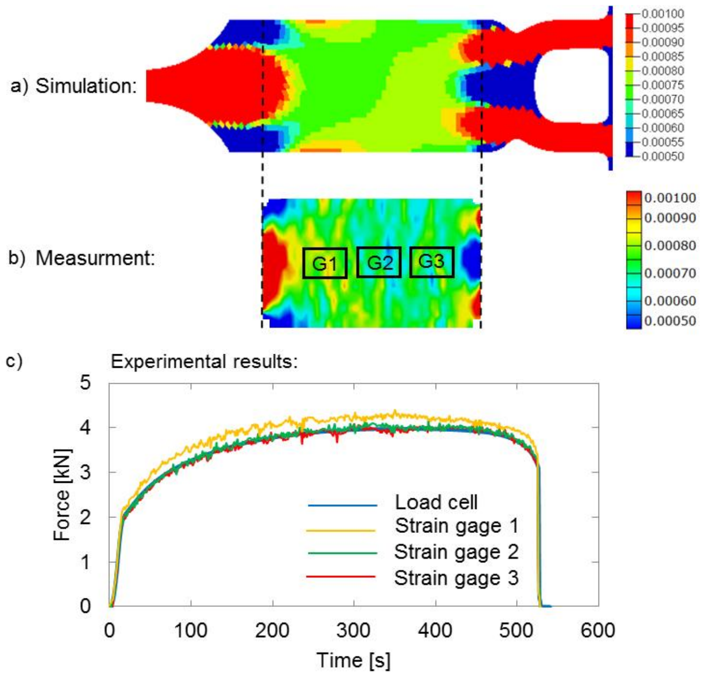

Figure 2: Special geometry for a homogeneous elastic strain field

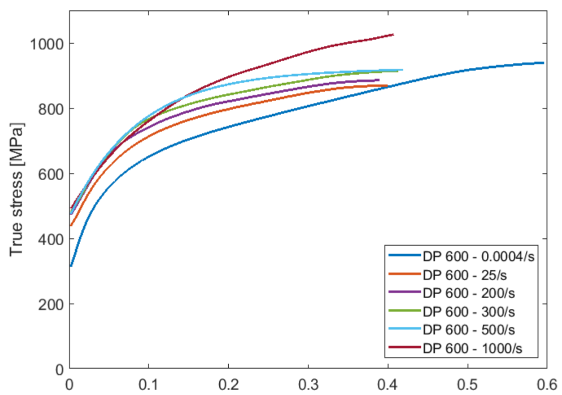

Figure 3: Example stress-strain curves of a dual phase steel DP 600

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