MATERIAL CHARACTERIZATION LEVELS FOR CRASHWORTHINESS APPLICATIONS

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ABSTRACT

During the last decades, numerical simulation of crash events has become one of the key topics in the reduction of costs for the phases of development of new automotive products. The former conception as a tool to provide qualitative support to designers has evolved up to the point of talking about "virtual testing" and about the feasibility of include it in standards and regulations. This evolution of the perspectives requires more and more predictive simulation models, leading to a continuous improvement in the mathematical reproduction of the physical reality.

Within this background, the correct numerical reproduction of the material behaviour has a critic role. The techniques for material characterization have also evolved from the use of simplified curves obtained from scarcely instrumented tensile tests, including strain rate dependency in a higher or lower degree, up to the use of complex yield surfaces obtained from the exhaustive analysis of the local phenomena that occur during the necking process in tensile tests, as well as the inclusion of other load cases different to the uniaxial tension.

The current paper reflects the results of some studies about the influence of different levels of material characterization on the correct reproduction of the material behaviour. The base case is the simulation of the characterization tests themselves, analyzing both local and global parameters for the validation of the models. Three different materials (one metallic and two plastics respectively) have been used in these studies, trying to deepen into their basic characteristics and requirements. Finally, a load case closer to a common energy absorption application has been chosen for the case of the plastics in order to illustrate and validate the hypothetical consequences of the use of the different material definitions.

INTRODUCTION

Numerical simulation is nothing else than a mathematical description of the reality. If we intend to reproduce mathematically the behaviour of a material working in a dynamic situation, first of all we will need to know how this material behaves in a similar range of mechanical conditions and, in second place, to determine a set of equations and parameters that serve us to describe the desired behaviour. One of the roles of the so-called material characterization process is to determine experimentally the response of the materials in a range of mechanical conditions and to use these data to obtain a reliable mathematical reproduction of it to be included in simulation codes. This short introduction is somehow obvious. Nevertheless, it helps us to remark the importance of using a correct mathematical description of the materials employed in simulation. Briefly, to include an incorrect material characterization in a simulation model would be the numerical equivalent to introduce a wrong plastic material in an injection machine.

Even though almost any experimental method producing plastic deformations on the material could be used for mechanical characterization purposes, tensile testing is probably the most employed way to describe the relationship between stress and strain in materials subjected to mechanical efforts. This experimental method provide us with very valuable information about the characteristics of the tested material up to its failure and rupture, allowing us to obtain data of different aspects of its elastic, plastic and damage behaviour. Besides, tensile tests are relatively simple of executing and measuring in comparison with other testing configurations, allowing a wide range of testing speeds and temperatures that cover the most common requirements of the automotive industry. As a consequence, one the most common ways of obtaining mathematical descriptions of materials to be used in numerical models for crashworthiness applications is based on the execution of groups of tensile tests at several speeds, with the aim of obtaining stress-strain curves for different constant strain rates.

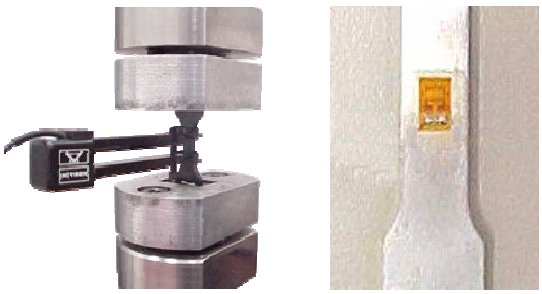
The exclusive use of the tensile test results for the mechanical characterization of the materials is based on the assumptions that the tensional state developed during this test is basically uniaxial, and that the relationship between stress and strain measured under these conditions can be used to create a description of the material behaviour representative of other load states, such as multiaxial loads, compression, shear, etc. The most extended mathematical transcription of these hypotheses is reflected on the isotropic elastic plastic laws. These laws, implemented in the most of the numerical simulation codes used for

crashworthiness applications ([1], [2] or [3] among others), use a quite simple description of the elastic behaviour that generally requires a set of only two parameters (i.e., Young Modulus and Poisson Ratio), whereas plastic behaviour is commonly described by a surface defined either by a mathematical expression or by a set of curves, representing the yield stress as a function of the effective plastic strain ant the strain rate. Commonly, Von Mises criterion [4] is employed to discern between both behaviours.

At this point, a link is needed to obtain the input for simulation from the experimental outputs. The most traditional way to do this is to estimate the true stress and plastic strain from the force applied to the tensile specimen (measured commonly with a load cell fixed to the testing machine) and the distance between two sections or points of the specimen, usually measured using an extensometer or another equivalent method and known as gage length. The expressions employed to perform these conversions are widely documented (e.g. [5] and [6], among many others) and there is no point in reproducing them here, but it is interesting to remember some of the assumptions that base these calculations: In the first place, the true strain, and consequently the true stress, are expected to be homogeneous between the sections measured with the extensometer. Secondly, the transversal area needed to calculate the true stress is normally unknown, so a hypothesis must be posed in order to estimate it from the original area and the engineering strain (measured on the longitudinal axis of the specimen). The most common suppositions are the hypothesis of constant volume and the hypothesis of elastic behaviour (depending on the particular case). Finally, an additional supposition is done related to the strain rate, which is implicitly supposed to be constant during the tests. This is done when true stress – plastic strain curves obtained from the experimental results are taken as representative of a unique strain rate associated to the test.

Although the underlying concepts of the previous methodology seem to appear very clear, there exist important issues that affect to the final result of the material characterization. On the one hand, the reliable acquisition of experimental data depends highly not only on the correct execution of the tests, particularly at the higher strain rates, but also on the adequate selection of the measurement methods and instrumentation. On the other hand, the treatment of the experimental results for the generation of numerical material laws can be done applying different methods, leading to different material descriptions.

Paying attention to the selection of the instrumentation, the correct measurement of the strain will play a fundamental role in the current analysis. Leaving out of consideration generic characteristics such as range, accuracy or dynamic response, we can classify strain measurement methods in “average” and “local” measurement methods (see Figure 1). The first group, which include the traditional extensometers, provide information about the relative displacement of two sections of the specimen, what in practise means that the measured strain is only representative of the average strain of all the material placed between both sections. The second group is composed by methods that provide information about the deformation of small zones of the specimen. The most classical example of these systems is the strain gauge.



Extensometer (average measurement) Strain gauge (local measurement)

Figure 1. Use of extensometers and strain gauges for measurement of strain in tensile tests.

Within the second category, it begins to be extended the use of specific software packages dedicated to provide a continuous field of deformation based on the photogrammetric analysis of digital video frames recorded during the tests. Further information about these methods can be found in [7] and [8]. Although this system has certain disadvantages with regards to the classical instrumentation, such as the accuracy at low strain levels or the need of an additional analysis process posterior to the test, at present it provides the most complete information about the local evolution of the strain on the whole surface of the specimen. These data are extremely valuable, since they allow the analysis of local phenomena (concretely the necking process), which often include information required for the characterization of the material at strain levels close to the rupture. A typical result from this kind of software can be observed in Figure 2.

In order to fully understand the scope of the previous affirmations, it is necessary to make a brief analysis of the necking phenomenon and its effects on the characterization process. This phenomenon, already documented in 1885 [9], could be very roughly described as a lack of homogeneity observed in specimens of ductile

materials before fracture occurs during tensile tests. At the beginning of these tests, the stress, strain and strain rate remain homogeneous in the whole zone of the sample destined for strain measurements. At this stage, average deformations are representative enough of the strain state of the material. Nevertheless, when the necking process starts, strain distribution begins to be heterogeneous and average measurements lose representativeness.

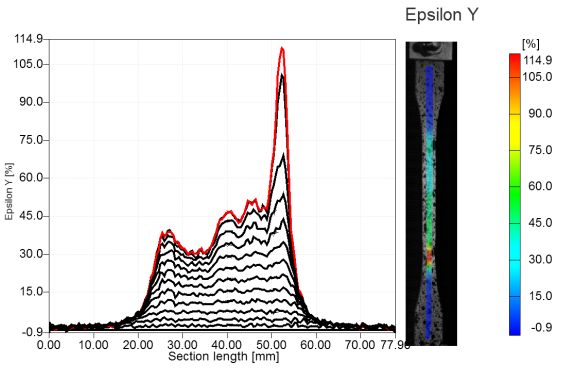


Figure 2. Output of software based on calculation of strain from image analysis

In a typical situation, the necking process begins when a limited zone of the specimen suffers a local increase of the plastic strain higher to the expected in a homogeneous deformation. This effect leads to the creation of the shape known as neck, where the distribution of the stress, strain and strain rate is not homogeneous any more. After this first nucleation of the neck, its evolution will depend highly on the characteristics of the material. In some materials, the plastic strain growth keeps concentrating on the central part of the neck, which evolves quickly up to the rupture. In order to establish a simplified nomenclature, we will refer to this behaviour as "Concentrated Neck". The result of this evolution can be a strongly heterogeneous distribution of the mechanical magnitudes along the specimen, invalidating the calculations based on the homogeneity of these magnitudes. This behaviour, characteristic of steels, can also be found in many plastic materials used in industrial applications.

On the other extreme of the behaviour of the ductile materials, the speed of the growth of the plastic strain at the original nucleus of the neck can descend due to microstructural reasons. In this case, the plastic strain of the central zone of the neck evolves more slowly, up to remain practically frozen in some cases ("blocking" of the neck). In the meanwhile, the neighbouring zones of the specimen begin to increase their plastic strain ("growing" of the neck). The macroscopic translation of this effect is an extension of the zone affected by the neck, which can expand even beyond the limits of the measurement zone of the sample. This transmission of the neck can occur in a way more or less gradual, producing a wide range of possible neck geometries. The softest cases of this phenomenon can lead to a practically homogeneous distribution of the mechanical magnitudes. We will refer to this situation as "Distributed Neck".

Figure 3 and Figure 4 show respectively some results of the simulations of quasi-static tensile tests considering two different plastic materials where both behaviours have been detected. It can be noticed the different distributions of the effective strain, and, the most important, how in the case of the distributed neck the average strain (measured with a simulated extensometer) is similar to the local strain observed at the neck, while in the case of the concentrated neck both magnitudes can differ considerably.

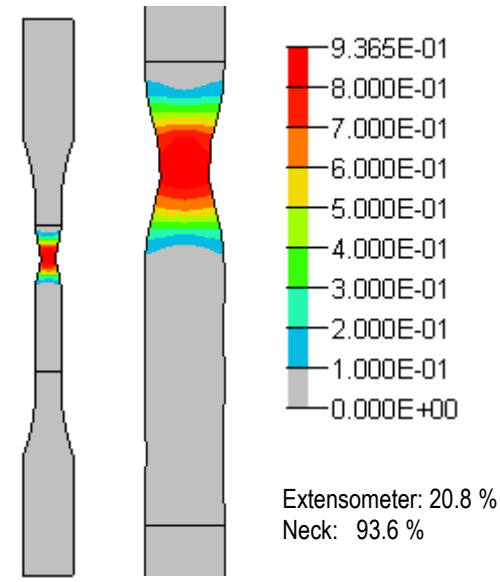


Figure 3. Effective strain distribution in a tensile specimen with concentrated neck.

As explained above, the most common implementation of plasticity in the simulation codes requires the definition of the yield stress as a function of the plastic strain and the strain rate. These data will define the plastic behavior of each element of the simulated material, independently of its size. According to the concept inherent to the Finite Elements Method, the parameters to be included in the modelization should be representative of the average behavior of the volume associated to the element. Therefore, if elements satisfy the premise of being small enough as to allow the correct reproduction of the experimental neck geometry with the numerical tensile specimen, then the values to be used should

be the ones corresponding to the average magnitudes in a quite small volume, what is equivalent to talk about local measurements.

DISTRIBUTED NECK (HCPP Copolymer)
Effective strain

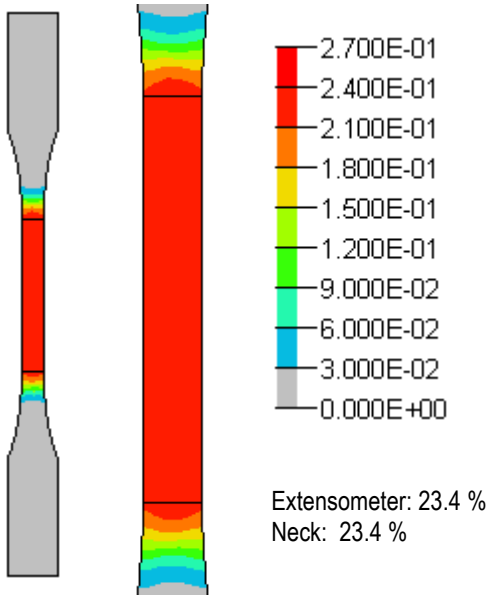


Figure 4. Effective strain distribution in a tensile specimen with distributed neck.

Obviously, the heterogeneity of the magnitudes does not affect exclusively to the strains, but also to any physical magnitude associated to them. Figure 5 and Figure 6 show that local distribution of the strain rate can also be very different to the average one. This fact affects particularly to our study, as our final aim is to obtain an expression of the real stress as a function of the plastic strain and the strain rate. The main conclusion to be extracted is that strain rate is subjected to local and temporal variations during the tests, and, consequently, its approximation by a constant magnitude implies a certain degree of error that will depend on the heterogeneity observed in the specimen.

Once arrived to this point, some important concepts have arisen related to the phenomenology of tensile tests and to the different options for strain measurement. Unfortunately, these concepts point to the fact that some of the hypotheses accepted by the traditional characterization methods are unrealistic in many practical applications. On the other hand, we have seen that additional experimental methods are available nowadays to measure local strains, and that, thanks to these methods, some of the assumptions required by the traditional methodologies are not needed anymore. All this leads to a situation where numerical materials characterized with both traditional and new methods coexist in data bases, either because of having been characterized years ago or because of having been characterized recently in laboratories still using traditional methods.

CONCENTRATED NECK (Talc filled PP Compound)
Strain rate

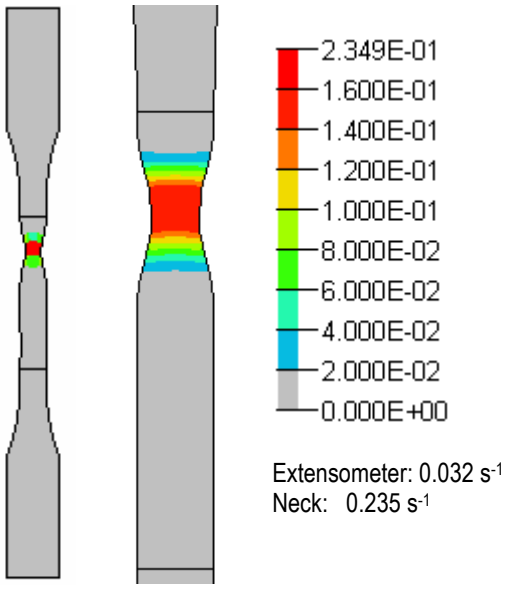


Figure 5. Strain rate distribution in a tensile specimen with concentrated neck.

DISTRIBUTED NECK (HCPP Copolymer)
Strain rate

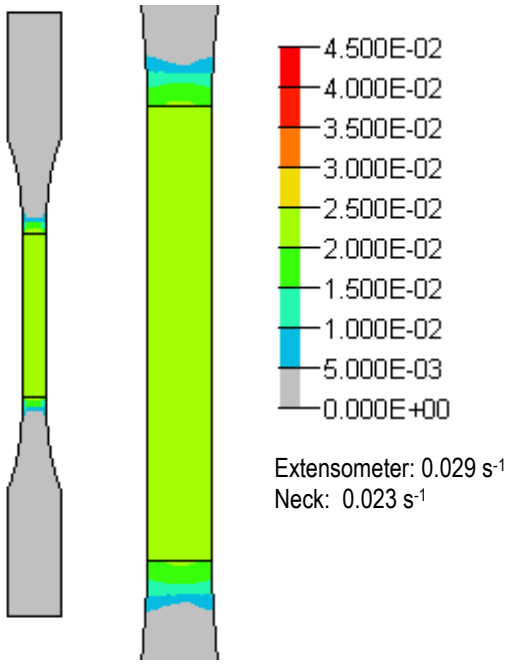


Figure 6. Strain rate distribution in a tensile specimen with distributed neck.

In a further step, it is also possible to eliminate the hypothesis of independence with the load

conditions (either uniaxial or multiaxial), leaving the use of classical elastic-plastic material definitions and using more advanced material laws (e.g. [10], [11]). Nevertheless, in spite of their promising capabilities, in practise the use of these laws is still not very extended.

Coming back to the original idea of obtaining a reliable numerical reproduction of the reality, some questions come immediately to mind: If there are diverse coexistent methods that lead to a range of possible characterization results, how do these different descriptions of the material behaviour affect to the accuracy of the final simulations? Up to present, simulation models based on traditional methods have provided reasonable results. Then, what are the advantages brought by these new methods?

Although these questions are almost philosophic and there will not be a general answer applicable to all the materials and applications, the studies presented in this paper try to outline a first quantification based on the application of different modelization techniques to a limited but heterogeneous array of materials and applications.

METHODS

The basis of the presented studies has been the selection of a group of materials, applications and characterization levels limited enough as to make affordable a detailed analysis of the different combinations, but at the same time varied enough as to be representative of a wide range of situations.

Three materials have been selected as representative of some of the behaviours to be analysed. All of them are commonly used in automotive applications. From now on, they will be referred as “Steel”, “Plastic 1” and “Plastic 2”. “Steel” is a high strength steel, “Plastic 1” is a plastic blend based on polyamide and ABS, and “Plastic 2” is a high cristalinity polypropylene copolymer. As seen in previous experiences with these materials, “Steel” presents the typical behaviour of steel, including the concentrated neck in tensile tests, while “Plastic 1” and “Plastic 2” present different degrees of distributed necks (in general, more homogeneous in “Plastic 1” and less in “Plastic 2”). These behaviours can be observed in Figure 7.

The applications selected for the study should be relatively simple, in order to be indicative of the influence of the material modelization, avoiding interferences of other less controlled parameters, such as contacts, frictions, etc. On the other hand, they should be demanding enough as to use a high proportion of the definition of the material in strain and strain rate and, in this way, to be more sensitive to possible different characterizations. Finally, they should be representative of different possible load states present in automotive typical applications.

Attending to these considerations, two test procedures were chosen. Tensile test was selected to be the first application because of obvious reasons: The load state is the same used for the characterization process, existence of very detailed experimental results and high demand on the material. For the second application, a test based on a drop test was chosen. In this test, a 20 Kg body with a flat surface falls over a piece whose geometry includes two conical shells that collapse during the impact. The geometry of this specimen prior and after the tests can be seen in Figure 8. Two different speeds have been used in order to produce different degrees of deformation in the material.

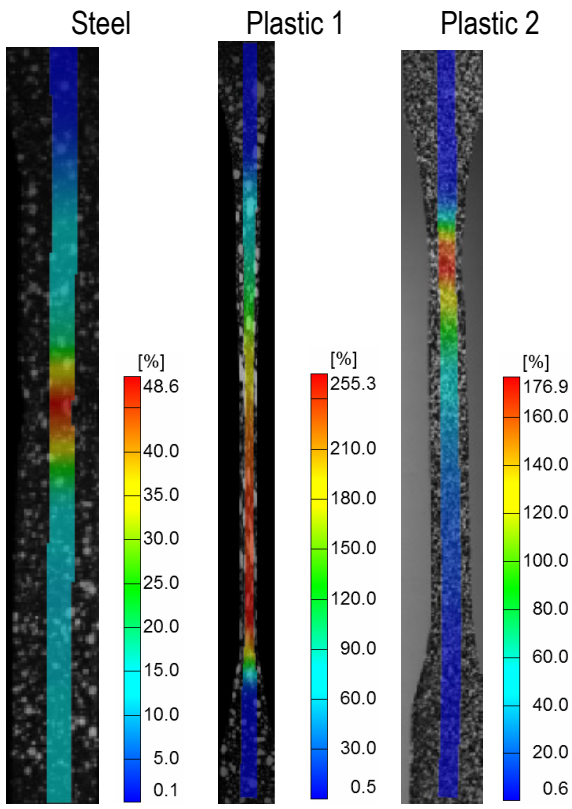


Figure 7. Distribution of local longitudinal strain in tensile specimens of the materials employed in the studies.

Figure 8. Energy absorption specimens before and after the higher speed drop tests.

The same experimental tests have been employed to obtain data for the different characterization options. For all the materials, tensile tests at between four and five different speeds have been performed, being the first of them quasi-static and the rest dynamic speeds. These speeds cover the most common strain rates required in crashworthiness applications. In all the cases, a minimum of three repetitions have been performed at each speed in order to consider possible variability of the materials. Also in all the cases, one high speed camera has been employed to record the temporal evolution of the deformation of the specimen, allowing the study of local strains and the simulation of the measurement registered by an extensometer, estimated through the motion of two points on the specimen surface situated at a distance of 25 mm, and placed around the central section of the specimen.

With regard to specimen geometries, 2 millimetre thickness ISO 527-2 1BA tensile specimens [12] were used for the characterization of the plastic materials, whereas 1 mm thickness samples were employed for the characterization of the steel, with a geometry based on three sections (5, 10 and 15 mm).

Three material characterization levels have been defined for comparison. They will be referred as Level 1, 2 and 3 respectively:

Level 1 corresponds to the most traditional methodology of material characterization. Strain data from the simulated extensometer are used. Strain rates are supposed to be constant and homogeneous during the entire tests. One curve is obtained corresponding to each tested speed and introduced into the material cards for the simulation input.

Level 2 is basically similar to Level 1, but local strains at the points of maximum deformation in the neck are used instead of extensometer values. The hypothesis of homogeneous distribution of strains along the specimen is consequently eliminated. On the other hand, constant strain rate is still accepted.

Level 3 removes at the same time the hypotheses of homogeneous strain and strain rates. Local strains are employed to calculate instantaneous and local strain rates. Points at several locations of the specimen are analysed in order to obtain different load conditions. All this information is combined to obtain a mathematical surface from which true stress – plastic strain curves at constant strain rates are obtained. This method allows the obtainment of a number of curves different to the number of speeds tested. Consequently, a more detailed description of the yield surface is given. Figure 9 and Figure 10 show typical yield surfaces obtained with this method for a metal and a plastic respectively.

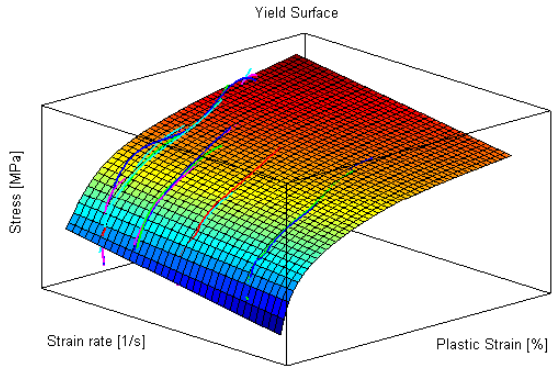


Figure 9. Typical shape of the yield surface of a high strength steel obtained with methods described as "Characterization Level 3".

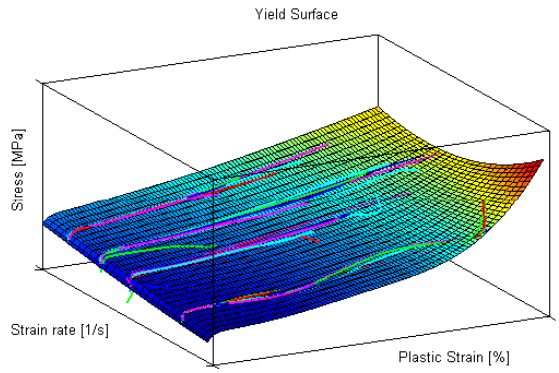


Figure 10. Typical shape of the yield surface of a plastic with behaviour near to elastomeric obtained with methods described as "Characterization Level 3".

One interesting point is that curves obtained with this method produce satisfactory results with a relative independence of the simulation code either for shell and solid elements. Some differences can be found in elements working with high deformations, when other factors not related to the material law acquire bigger influence on the deformation of the elements. Figure 11 shows the results of the simulation of dynamic tensile test performed on steel specimens. Three experimental repetitions are shown, referred as "EXP 1, 2 and 3". Next to them appear the results of a set of simulations using three simulation codes of extended use in automotive. Figure above shows the numerical results using models of specimens defined with shell elements, while figure below displays the same results using solid elements. The same stress-strain curves have been used in all the elastic-plastic material laws employed for the different simulations. As can be observed, despite small deviations due to the different

implementations employed, all numerical results reproduce quite satisfactorily the experimental curves.

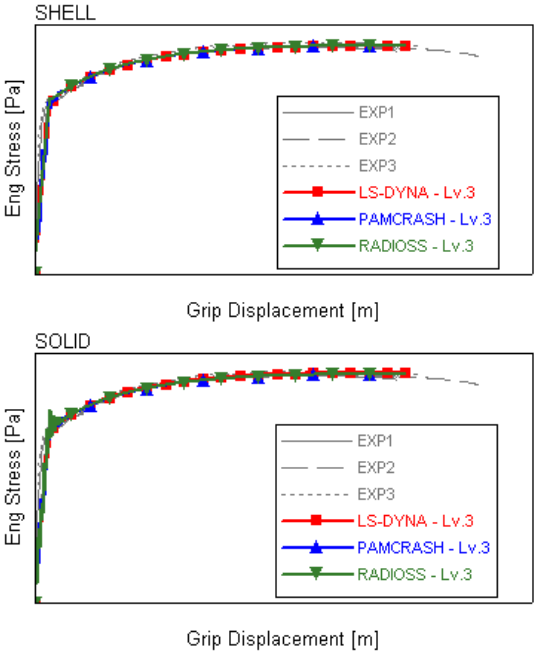


Figure 11. Results of simulation of dynamic tensile tests of a metallic material using different codes and element types (Characterization Level 3").

All the simulations presented henceforth in this document have been performed using the software LS-DYNA. Shell and solid elements have been employed in studies, using in all the cases the material type 24 (Piecewise Linear Plasticity). The use of parameters or material laws associated to damage and rupture has been avoided in order to obtain a major representativeness of the influence of the original yield surface, in spite of a possible loss of accuracy on the reproduction of the behaviour just previous to the failure.

TENSILE TESTS

The first of the applications to check the differences between the characterization levels is the numerical reproduction of the tensile tests from which characterization data were obtained. Mesh size used for the definition of the models has been chosen small enough as to allow a reasonable representation of the geometries adopted by the specimens during the necking process. Figure 12 and Figure 13 display the meshes of solid elements employed in the models of tensile tests. Simulations have been made in parallel using similar specimens with shell elements.

Engineering stress versus grip displacement curves have been chosen for validation purposes because of their representativeness of the whole behaviour of the specimen. Additionally, local strain contours have been checked in order to analyse the distribution of the loads in the specimen.

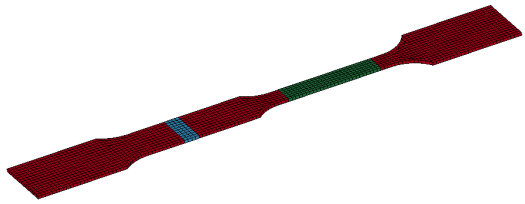


Figure 12. Mesh employed in the simulation of tensile tests of Steel material (solid elements).

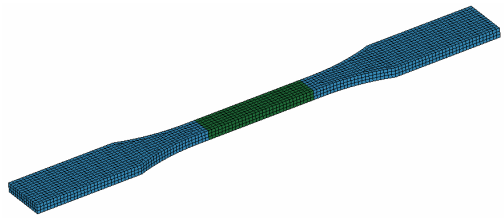


Figure 13. Mesh employed in the simulation of tensile tests of Plastic 1 and Plastic 2 materials (solid elements).

Steel

As mentioned before, steels are a typical case of concentrated neck. Figure 14 displays the strain measured at one of the dynamic speeds tested. Two different stages can be differenced paying attention to this graphic. During the first part of the test, local strains coincide with the measurement of the extensometer. This indicates that deformation is approximately uniform. After the initiation of the necking process it can be observed how local strain and extensometer begin to diverge, being the difference quite important just before the rupture occurs. The consequence of this effect on the different characterization options should be a divergence of the results after the creation of the neck, prior to the rupture.

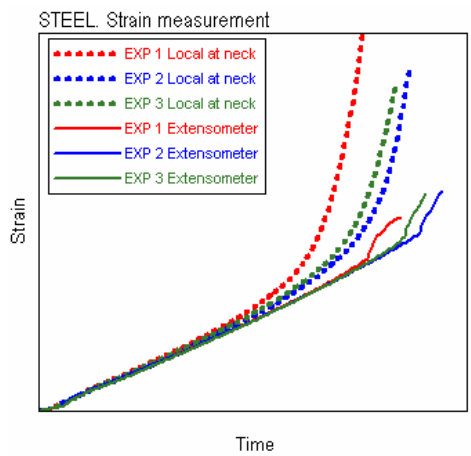


Figure 14. Different experimental strain measurements of Steel (Dynamic 1 s^{-1}).

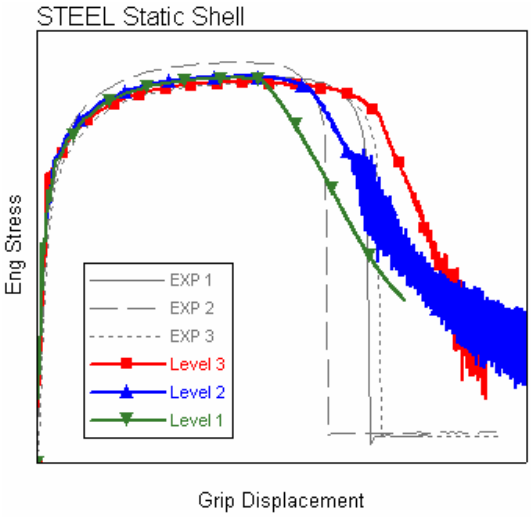


Figure 15. Tensile test of Steel (Static). Shell elements

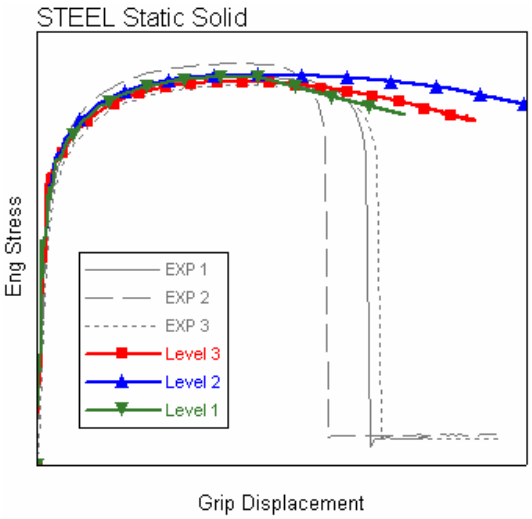


Figure 16. Tensile test of Steel (Static). Solid elements

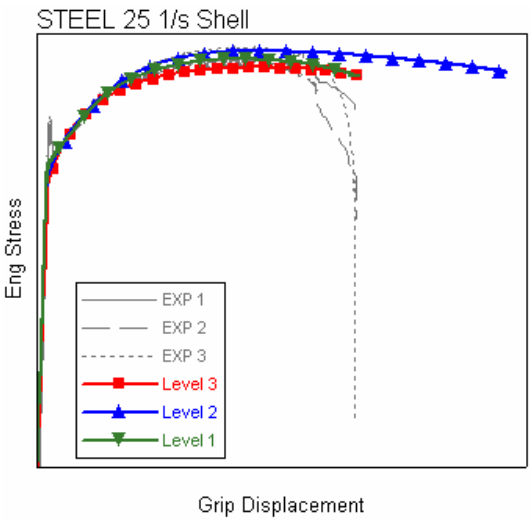


Figure 17. Tensile test of Steel (Dynamic). Shell elements

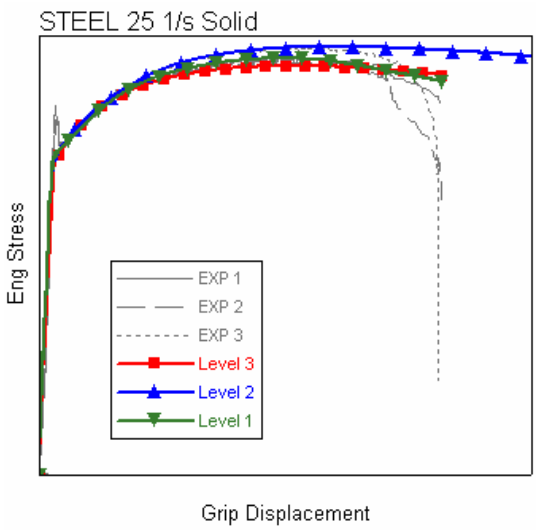


Figure 18. Tensile test of Steel (Dynamic). Solid elements

Paying attention to the element type, we can see that, in general, shell elements initiate the descending part of the presented curves before than solid elements, and that, in short, there is some divergence in the behaviour of the specimen not associated to the yield surface, which is actually the same.

Plastic 1

The behaviour observed in Plastics 1 and 2 is more complicated than the studied in the previous case. While in Steel material neck concentrated up to the rupture point, in a typical plastic the neck extends to other sections of the specimen, producing effects of blocking and growing more complex to measure and to adjust numerically.

Tensile tests performed on Plastic 1 have exhibited different tendencies depending on the strain rate. At low strain rates neck has tended to more distributed and homogeneous neck shapes (like the one shown in Figure 7), while at higher strain rates the tendency has been to a higher concentration, although not as marked as in Plastic 2. This translates into a higher homogeneity of the results between the options based on local strain measurement (Levels 2 and 3) and extensometer (Level 1) for the static situations, next to a lower homogeneity at higher strain rates. In any case, only characterization of Level 3 has been able to reproduce satisfactorily the phenomenology in all the cases. Figure 19 to Figure 22 illustrate these observations, displaying results for static and dynamic tests, as well as for shell and solid elements.

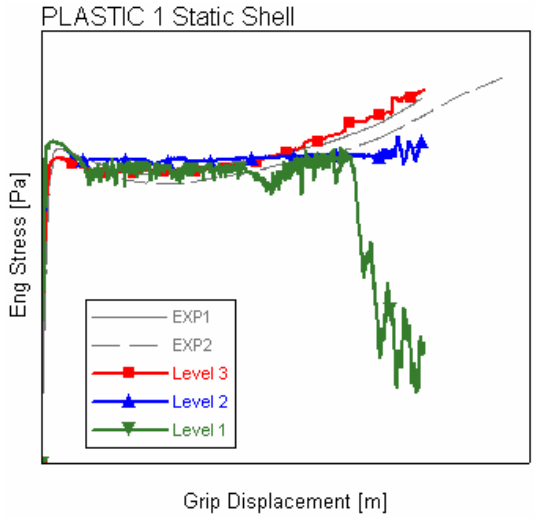


Figure 19. Tensile test of Plastic 1 (Static). Shell elements

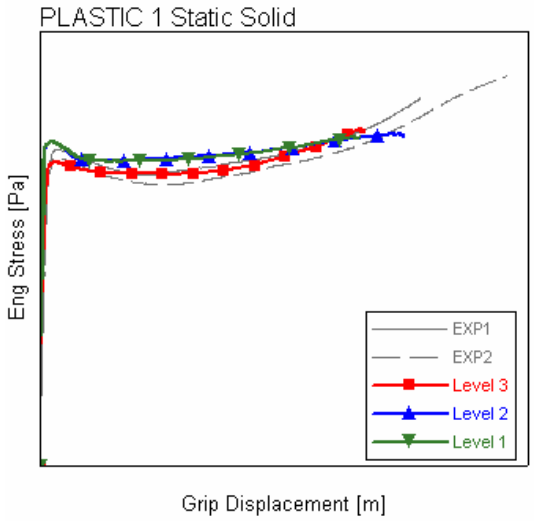


Figure 20. Tensile test of Plastic 1 (Static). Solid elements

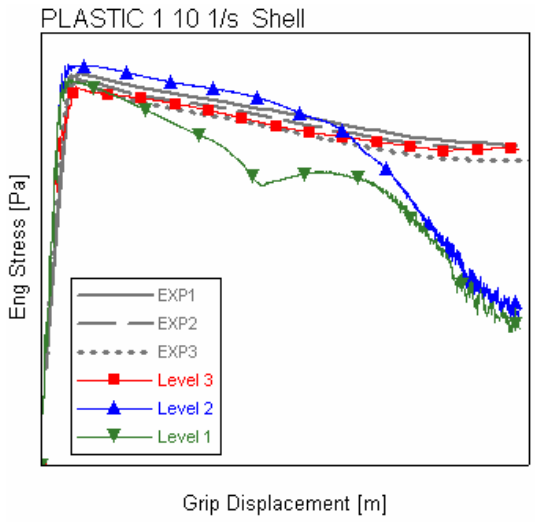


Figure 21. Tensile test of Plastic 1 (Dynamic). Shell elements

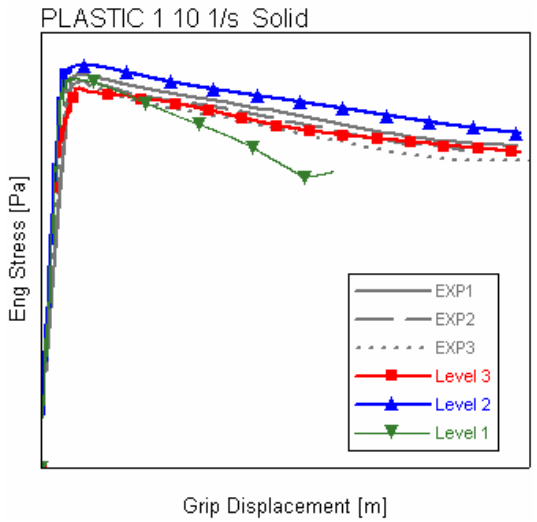


Figure 22. Tensile test of Plastic 1 (Dynamic). Solid elements

Plastic 2

Plastic 2 offers a good sample of concentrated neck in plastic materials (see Figure 7). As already explained, this implies possible important differences between local strains measured in different sections of the specimen. Therefore, curves defining yield surfaces between characterization options based on both measurements could be substantially different.

As with the precedent materials, Figure 23 to Figure 26 show the results of the simulations of static and dynamic tensile tests using both shell and solid elements. As expected, results correspondent to characterization Level 3 offer in all the cases a more realistic reproduction of the experimental observations.

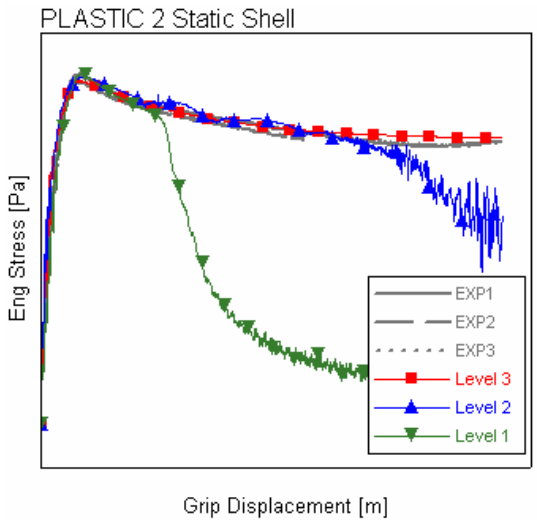


Figure 23. Tensile test of Plastic 2 (Static). Shell elements

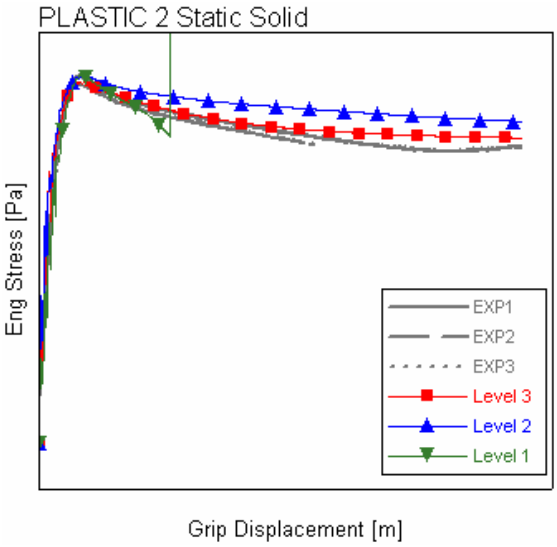


Figure 24. Tensile test of Plastic 2 (Static). Solid elements

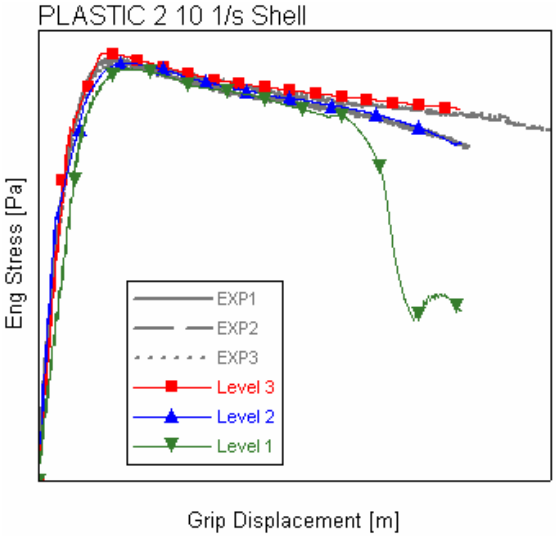


Figure 25. Tensile test of Plastic 2 (Dynamic). Shell elements

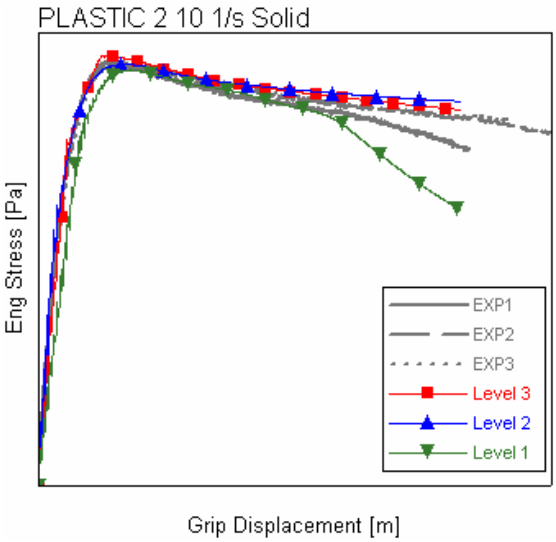


Figure 26. Tensile test of Plastic 2 (Dynamic). Solid elements

As can be seen in the figures, Level 1 characterization has produced quite deficient results in static tests for both types of elements, leading even to instabilities in the case of the solid elements (this is the cause of the vertical line in Figure 25). On the other hand, dynamic results are not so bad, in spite of the differences between local and average deformations.

ENERGY ABSORTION TESTS

A second application has been chosen in order to provide further information about the effective influence of the material characterization on the accuracy of the numerical models, looking at the same time for load states different to the uniaxial tension, analysed in the tensile tests. With this aim, guided drop tests have been performed on conical specimens (see Figure 8). These specimens are used for the analysis of energy absorption capabilities of different materials. In these tests the material works mainly under compressive and flexional loads, being different to the one employed for characterization. Therefore, the degree of realism of the hypothesis of equal response to different load states, assumed by the elastic-plastic law, can affect to the accuracy of the numerical results. As mentioned before, although there are material laws taking into account this phenomenon, the current study has been limited to the more extended elastic-plastic laws.

The drop tests have been performed only with plastic materials. Two speeds of the impactor have been tested with each material. The first of them, referred ad "High demand tests", produces the almost complete collapse of the smaller cone. The second speed, referred as "Medium demand tests", produces an intermediate deformation of the specimen. Figure 27 shows two specimens of Plastic 1 after both types of tests. Due to the different characteristics of both plastics, different speeds have been used with each one of them.

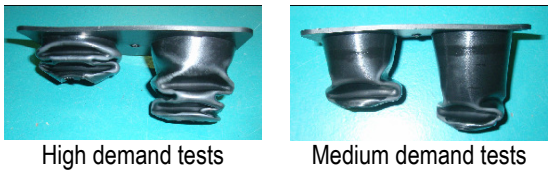


Figure 27. Specimens of Plastic 1 after Medium and High demand tests.

The numerical simulation of the tests has been performed using shell elements and the same material cards employed in the first application. Two states of one of these simulations can be seen in Figure 27. Figure 28 shows a comparison between the geometries achieved experimentally and numerically.

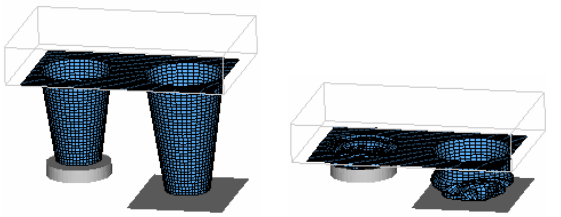


Figure 28. Model employed in the simulation of the drop tests. (Plastic 1, High Demand)

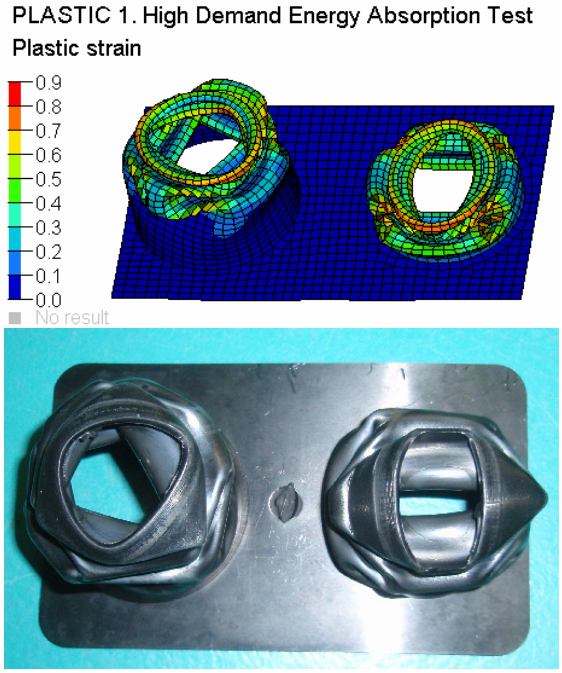


Figure 29. Numerical (Level 3) and physical specimens after High Demand energy absorption test (Plastic 1)

Curves representing force on the impactor versus its displacement are used for comparison purposes. These curves are representative of the energy absorbed during the process, and allow a quick check-up of the behaviour of the specimen during its collapse. A very interesting indicator is the maximum displacement, which basically coincide with the length collapsed by the specimen to absorb the kinetic energy of the impactor. Experimentally, both force and displacement have been calculated from acceleration signals on the impactor, as well as from the measurement of the speed just before the impact with the specimen.

Plastic 1

Figure 30 and Figure 31 display the results for the energy absorption tests performed on Plastic 1. On them, particularly in Figure 30, it can be seen that the influence of the characterization level on the effective curves is almost negligible.

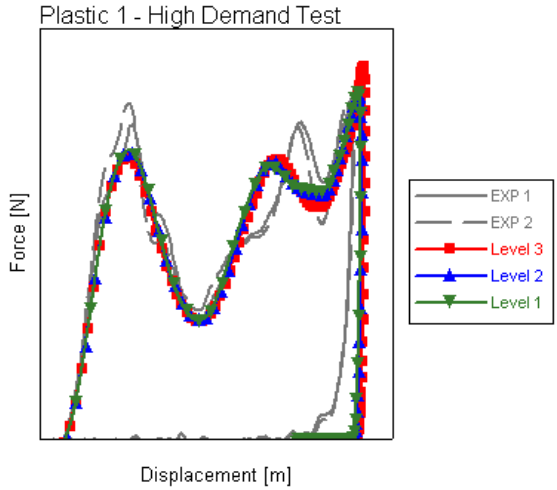


Figure 30. High Demand Energy Absorption tests of Plastic 1.

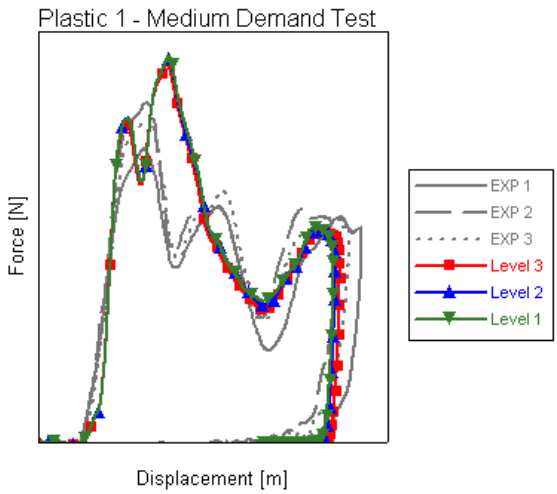


Figure 31. Medium Demand Energy Absorption tests of Plastic 1.

The results obtained are easily explained paying attention to the evolution of the magnitudes during the collapse of the cones and to the observations made for the case of the tensile tests. Peaks of force are produced by the resistance of the material to produce new folds, whereas valleys are produced during the bending process, when the material is sagging, and finish when the fold is completely formed and there is contact between zones of the plastic wall. This means that during the formation of peaks the process is governed by material zones with none or small plastic strain and low strain rates (material is still resisting or initiating the folding). As observed for this material in the first application, results were quite homogeneous at low strain and strain rates independently of the characterization level. This is in accordance with the observations made in this new case.

Plastic 2

The results of the drop tests for Plastic 2 are shown in Figure 32 and Figure 33. It can be observed that in this case there is a clearer influence of the characterization method on the final results of the simulation. It can be also noticed that experimental behaviour has been better reproduced by Level 3, particularly paying attention to the maximum deflection of the cones.

As for Plastic 1, the results are perfectly coherent with the observation made for tensile tests. In the case of Plastic 2, the static tests showed a big influence on the material characterization level due to the differences between local and average strains at the neck. This effect can be seen here again, producing differences on the simulation of the drop tests much more marked than the ones observed for the case of the Plastic 1.

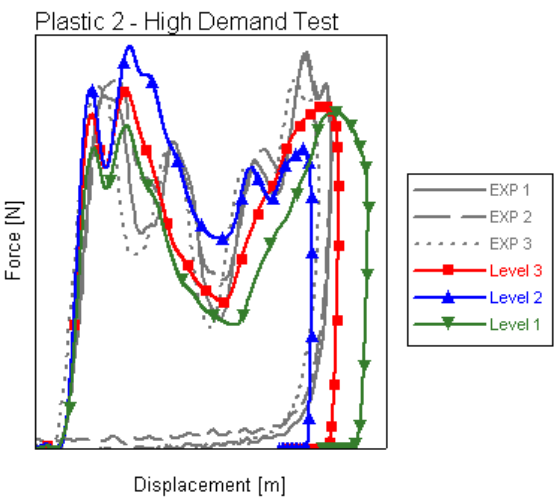


Figure 32. High Demand Energy Absorption tests of Plastic 2.

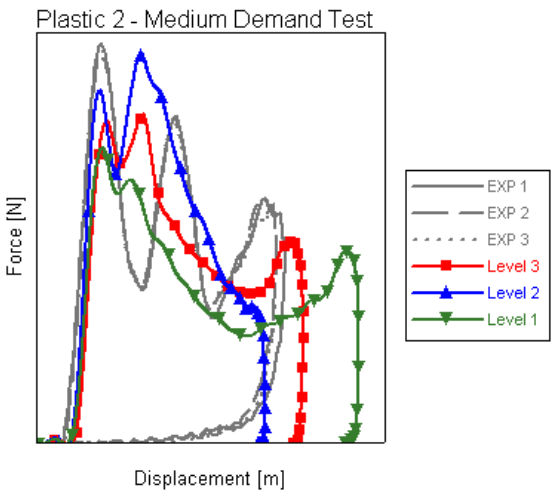


Figure 33. Medium Demand Energy Absorption tests of Plastic 2.

CONCLUSIONS

As introduced initially, experimental methods and expressions used traditionally for the characterization of materials are based on a certain number of hypotheses, which can be more or less realistic depending on the material simulated. Current methodologies include state of the art experimental and numerical techniques that allow the exclusion of some of these assumptions, leading to presumably more accurate material descriptions. The presented study tries to outline an answer to the question of how much these different models obtained for the same material affect to the accuracy of the results when used in the simulation of physical events.

Three characterization levels have been defined based on the use of tensile tests. The first of them (Level 1) coincides with the traditional methods (average strain estimated by the displacement of two sections of the specimen and constant strain rate). In the second one (Level 2), the hypothesis of homogeneous deformation has been removed thanks to the use of local strain measurement methods. In the Level 3, the hypothesis of homogeneous and constant strain rate has also been eliminated by the use of specific mathematical algorithms for the analysis of the experimental results.

These different characterization methods have been applied to three different materials (one high strength steel and two different plastics), looking for the representativeness of the study in different cases. The resultant material models have been used for the simulation of two different applications. The first of them has consisted in the reproduction of some of the tensile tests that served for the characterization of the materials. Two different testing conditions (static and dynamic) have been evaluated. The second application has been the simulation of drop tests used for the analysis of energy absorption. As before, two different speeds have been tested and simulated, although only the plastic materials have been considered this time.

After the results obtained in the simulation of the tensile tests, it has been observed how the differences between local and average strain measurements have shown to be decisive in the good reproduction of the experimental results. As predictable, the good correlation between different characterization levels was in general related to the homogeneity of the material behaviour during the formation and progress of the neck (for instance, the first part of the curves in “Steel” material or the static case in “Plastic 1”). Differences have been

also found when using solid and shell elements, associated normally to a more realistic behaviour when using the first ones. In general, only characterization Level 3 has shown to produce good results in all the evaluated cases.

When going to the second application, previous observations have been easily translated to the new situation. On the other hand, it has been demonstrated that phenomena occurring during these test are mainly controlled by material zones working at low plastic strain and strain rates, making this application less representative of the whole characterization of the material than expected. In any case, Level 3 characterization has shown again to produce more accurate results in independence of the material. As predictable, it can also be concluded that the final influence of the characterization method will depend on the simulated application.

In summary, although good results have been obtained by traditional characterization methods in cases when the assumed hypotheses were near to reality, only the elimination of these hypotheses has proved to provide good results in all the evaluated situations. This has seen to be particularly relevant in the simulation of the complex phenomenology associated to the plastics.

REFERENCES

[1] (2006) "LS-DYNA Theory Manual". Livermore Software Technology Corporation. ISBN 0-9778540-0-0

[2] (2006) "PAM-CRASH PAM-SAFE Solver Notes Manual". ESI Group. Release June 2006

[3] (2008) "RADIOSS Theory Manual 9.0 Version. Large Displacement Finite Element Analysis PART 2". Altair Engineering, Inc. Release January 2008.

[4] von Mises, R. (1913). "Mechanik der Festen Korper im plastisch deformablen Zustand". Göttin. Nachr. Math. Phys., vol. 1.

[5] Mase, G. E. (1970). "Continuum Mechanics". McGraw-Hill. ISBN 0070406634

[6] Rees, D. W. A. (2006). "Basic Engineering Plasticity - An Introduction with Engineering and Manufacturing Applications". Butterworth-Heinemann. ISBN 0750680253.

[7] Tyson J., Schmidt T., Galanulis K., (2002) "Advanced photogrammetry for robust deformation and strain measurement", Society for Experimental Mechanics (SEM) Annual Conference. Milwaukee, WI. USA.

[8] Schmidt T., Tyson J., Galanulis K., Revilock D. and Melis M. (2004). "Full-field dynamic deformation and strain measurements using high-speed digital cameras". SPIE 26th International Congress on High-Speed Photography and Photonics. Alexandria, VA. USA.

[9] Considère, A.G. (1885). "Memoire sur l'Emploi du Fer et de l'Acier dans les Constructions". Annales des Ponts et Chaussées, ser. 6, 9.

[10] Kolling S., Haufe A., Feucht M. And Du Bois P. A. (2005). "SAMP-1: A Semi-Analytical Model for the Simulation of Polymers". LS-Dyna Anwenderforum. Bamberg. Germany.

[11] Ratai A., Kolling S., Haufe A., Feucht M. And Du Bois P. A. (2008). "Validation and Verification of Plastics under Multiaxial Loading". LS-Dyna Anwenderforum. Bamberg. Germany.

[12] (1993) "Plastics -- Determination of tensile properties -- Part 2: Test conditions for moulding and extrusion plastics". ISO 527-2:1993 Standard.