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Elasto- Plastic Strain Rate Dependent Material Characterization of Steel Grade for Crash Simulation

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ABSTRACT

Strain rate sensitivity is an important material property in the formability of sheet metal. In this study, strain rate sensitivity is evaluated for grade of mild steel. Positive strain rate sensitivity results in a significant increase in the yield strength and tensile strength at higher strain rates. Material testing standards for quasi-static rates are relatively well established. The increasing need for high strain rate material properties is now focusing the engineering community's attention on the test methods used to generate data. The lack of industrial standards for high strain rate testing makes it vital that the end-user understands the valid applications and limitations of high strain rate material data. Current test methods, proper specimen selection, strain measurement methods, data analysis techniques, and interpretation of high strain rate data are reviewed. This dissertation deals with the effects of approaches for modeling of strain rate effects for mild steel on impact simulations. The material modeling is discussed in the context of the finite element method (FEM) modeling of progressive crush of energy absorbing automotive components. The characteristics of piecewise linear plasticity strain rate dependent material model are analyzed and sub-models for modeling of impact response of steel structures are investigated. The dissertation reports on the ranges of strains and strain rates that are calculated in typical FEM models for crush box and their dependence on the material modeling approaches employed. The models are compared to the experimental result and test on drop rig facility.

Keywords— **Crash Simulation, Dynamic Loading, Ls-Dyna, Material**

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I. INTRODUCTION

Crashworthiness of traffic vehicles is essential to save occupants' lives in an accident. The process of crashing energy absorption must be evaluated correctly and properly reflected in structural design. Mechanical characterization for structural materials in dynamic uniaxial tensile loading condition is one of the most practical themes to be investigated thoroughly. In the current automobile industry material testing standards for quasi-static rates are relatively well established. The increasing need for high strain rate material properties is now focusing the automobile industry attention on the test methods used to generate data. Many automobile industries are using different procedures and analysis may yield information in apparent conflict with other published data. There is lack of industrial standards for high strain rate testing makes it vital that the end-user understands the valid applications and limitations of high strain rate material data. Currently using test methods, proper specimen selection, strain measurement methods, data analysis techniques, and interpretation of high strain rate data need to review and to validate for crash applicationIn the current automobile engineers have more depended on the numerical simulation to help predict the crashworthiness of new vehicle designs, One of the benefits of using numerical simulation is not only to predict the crash behavior of vehicles, but also to understand and the effect of various design variables on the vehicles crash performances. Also replacing the expensive prototype testing with cost effective numerical simulation can not only reduced design and development times but also create opportunities for cost

Saving in the design and development process, Therefore by using numerical simulation tools effectively the potential exists for automotive engineers to be able to quickly design lower cost and better vehicles. In the recent years commercially available explicit finite element method or codes have been used to perform detailed numerically crash simulations. Several codes like Radioss, PamCrash, and LS-Dyna [16] are being used today in the automotive industry for crash simulation [8].

Because an automotive crash is a complex dynamic phenomenon the accuracy of a finite element simulation depends on a large number of factors. For example boundary conditions element size and formulations, and material constitutive model all may have an influence on the accuracy of any given simulation. The effect of mesh size can be quantified by varying the mesh density of a given model and comparing the results to either known solution or to experimental data. However varying the mesh size for an entire automotive vehicle system made up of several components would be impractical Likewise, evaluating the materials constitutive laws for the every material in an automobile, over entire range of strains and temperature experiences during the crash event would also be very difficult. However, large portion of an automobile comprised of steel and thus a large portion of the crash performance can be expected to be determined by steel material properties. Because crash event is dynamic, it can be expected that the material behavior of steel during crash will be strain–rate dependent. Currently, piecewise linear formulation (PL), Cowper-Symonds (CS) , Johnson-Cook (JC) and Zerilli-Armstrong material models are used for material modeling for numerical analysis [8].

This study deals with the effects of various approaches for modeling of strain rate effects for mild steels on impact simulations. In this context to modeling the strain dependent material we tested five standard specimens on high strain machine, at different strain rate and generate the stress-strain curve at each strain rate. The implementation of strain rate effects of material models used in LS-DYNA [16] can be fulfilled in a variety of different ways. Besides a table like input of piecewise linear stress strain curves for different strain rates, a choice of different constitutive equations is available. The choice of these constitutive equations and the determined constants affect the ability to accurately predict the behavior of the steel components during the crash event. The material modeling is discussed in the context of the finite element method (FEM) modeling of progressive crush of energy absorbing automotive components. The characteristics of piecewise linear plasticity strain rate dependent material model are analyzed and various sub models for modeling of impact response of steel structures are investigated. The models are compared to the experimental results from drop tower tests. Thus by analyzing and testing a small steel component subjected to crash event and some influence of constitutive relation on the finite element analysis result can be discussed.

II. GENERATE MATERIAL DATA

A. *Strain Rate Characterization*

Strain is a measure of the amount of deformation that occurs when an object is placed under stress. Strain rate is defined as the change in strain over the change in time. All materials will undergo some change in their dimensions when exposed to stress. The deformation caused by stress can be fully reversible or permanent; depending on the amount of stress applied .Elastic strain occurs when a material under stress returns to its original dimensions once the stress is removed. Plastic strain occurs when an object has been exposed to very high levels of stress and will no longer return to its original shape after the stress is removed. In many materials, the reversal of elastic strain is instantaneous, meaning it occurs without a perceptible duration of time. Deformation that is fully recoverable, but occurs over time, is described in terms of the strain rate. Strain rate varies widely for different materials, and will often change at different temperatures and applied pressures. Steel is an example of a material that returns to its original state immediately after stress is removed. A material whose rate of strain changes a large amount at different temperatures and pressures has high strain rate sensitivity. This rate is also dependent on the way the force or stress is applied. For many plastics, if a gradual stretching force is applied the material will elongate a large amount before it breaks. This is because the molecules in the plastic have enough time to reorient themselves and move past each other, causing the stretching to occur. If an impact or sudden force is applied to a plastic, it will break immediately and behave like a brittle material. The same plastic materialcan react very differently because of the different rates of strain caused by the way the stress is applied.

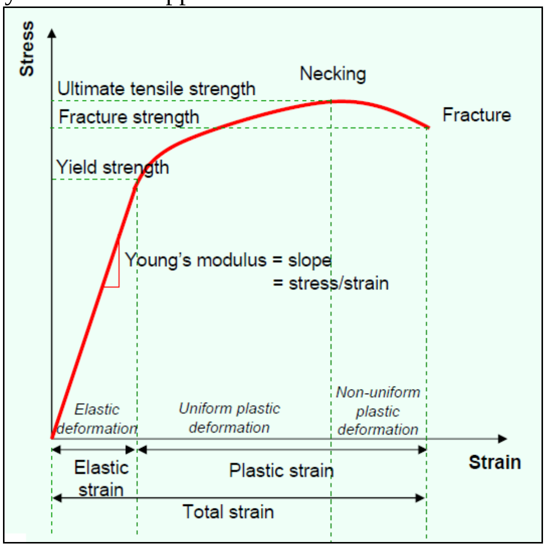


Fig.1 Engineering stress-strain curve

Strain rate can be measured in the laboratory using special test equipment that applies very precise loads to a sample, while measuring the deformation and recovery that occurs after the stress is removed. Since the strain rate of a material will influence how it behaves, it is important to understand its sensitivity to the type of load, amount of stress, and temperature. Understanding the strain rate of a material will ensure that it meets the performance specifications required in the end-use application.

B. *High Strain Rate Machine*

Crashworthiness is a key part of the design of a modern automobile. Under crash conditions, structural materials are subject to very high rates of strain and loading. Many material properties, including those of the steel or aluminum used in the automobile body, are strain rate sensitive. Consequently, quasi static stress strain data may not produce accurate predictions of behavior at high strain rates, and the use of such data in the analysis and design of dynamically loaded structures can lead to cautious overweight designs or premature structural failure. Servo hydraulic high rate systems provide metals with extensive capabilities for impact and high strain rate testing. The VHS systems are also able to be configured to perform tests from quasi static to impact speeds, as well as providing a cyclic testing capability. The systems incorporate a very high performance hydraulic actuator, featuring hydrostatic bearings and a seal less piston rod please refer fig. 2. With high performance control valves, these systems can be configured for speeds up to 25 m per second. Combined with a high stiffness two or four column load frame, the advanced 8800 control system and Profiler software can assist you in achieving near constant velocity. Patented 'Fast jaw' grips are utilized to instantaneously grip the specimen once the actuator has reached the correct velocity for the test. Testing forces are measured using high stiffness piezoelectric load cells and a high speed data collection system that records the entire stress strain curve at rates up to 5 MHz. These features allow metals to evaluate their materials at a level of detail never before possible. In order to perform high rate tests, we suggest using our High Rate software Program operating under Console software. These provide a single user interface for test set up, firing, data collection and viewing. We suggest using Impulse Software for advanced analysis technique.

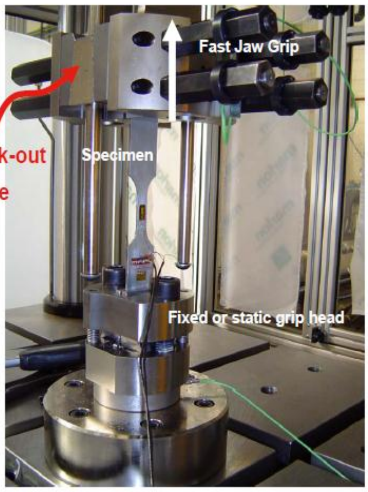


Fig.2 High Strain Rate machine by INSTRON

1) Features:-

- Capacity: 40 kN to 100 kN
- Capable of velocities up to 25 m/s
- Specialized measurement transducers
- Patented Fast Jaw gripping techniques
- High-speed data acquisition package
- VHS8800 controller package
- High-Rate Software
- Unique profiling capability
- Systems are contained by a protective enclosure to ensure operator safety
- High-stiffness load frames
- Unique actuator packages featuring
- Hydrostatic bearings, hydraulic cushionsand a Seal design
- Operates at a 280 bar supply pressure that results in higher acceleration velocity and load performance

C. Specimen Design for High Strain Rate Testing

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials.

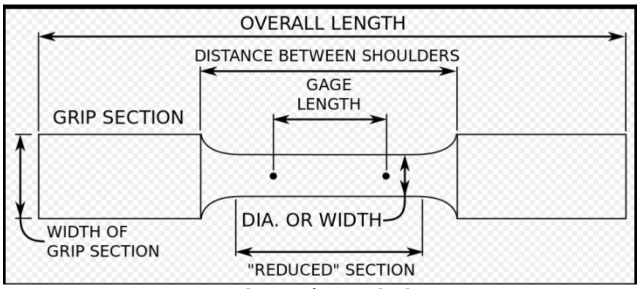
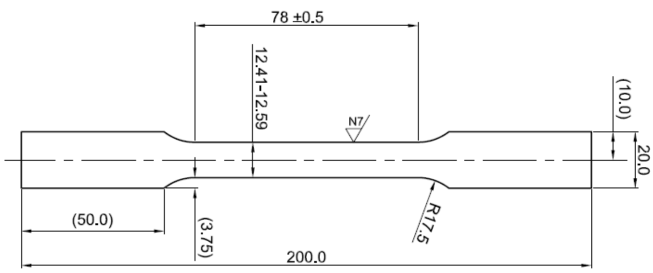


Fig.3Nomenclatures for standard specimen

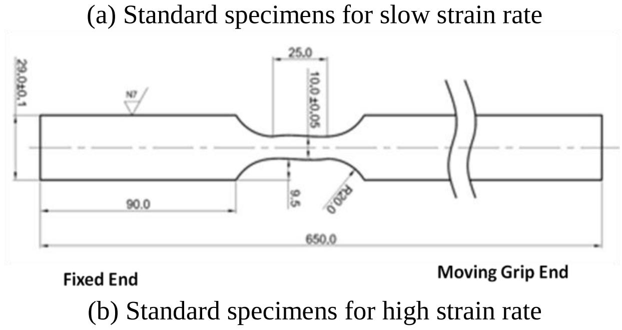
A tensile specimen is a standardized sample cross-section. It has two shoulders and a gauge (section) in between as shown in fig.3. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area. The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine. Each system has advantages and disadvantages; for example, shoulders designed for grips are easy and cheap to manufacture, but the alignment of the specimen is dependent on the skill of the technician. On the other hand, a pinned grip assures good alignment. Threaded shoulders and grips also assure good alignment, but the technician must know to thread each shoulder into the grip at least one diameter's length, otherwise the threads can strip before the specimen fractures. In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it. These specimens may not be exact representation of the whole work piece because the grain structure may be different throughout.

As shown below fig.4 (a) and (b) is the typical standard specimen used for the tensile testing at slow strain rate and high strain rate. For the slow strain rate specimen total length is around 200mm and for high strain rate specimen length is around 650-700mm. the gauge length is kept 78mm for slow rate and 25mm for the high strain rate.

Typical standard specimen for testing:-



(a) Standard specimens for slow strain rate



(b) Standard specimens for high strain rate

Fig.4 Typical standard specimens for testing

D. Digital Image Correlation

Digital image correlation and tracking is an optical method that employs tracking and image registration techniques for accurate 2D and 3D measurements of changes in images. This is often used to measure deformation (engineering), displacement, strain, and optical flow, but it is widely applied in many areas of science and engineering. Digital image correlation (DIC) techniques have been increasing in popularity, especially in micro- and nano-scale mechanical testing applications due to its relative ease of implementation and use. Advances in computer technology and digital cameras have been the enabling technologies for this method and while white-light optics has been the predominant approach, DIC can be and has been extended to almost any imaging technology.

Fig.5. Setup for Digital image correlation

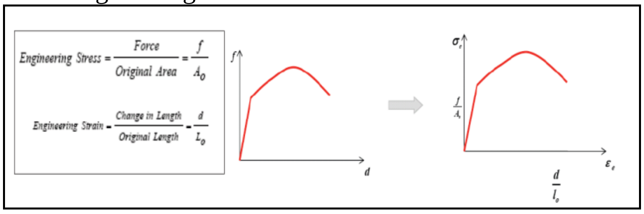
III. MATERIAL MODELLING

For the determining true stress-strain curves from flat tensile specimens beyond the onset of necking has been investigated based on finite element analyses under consideration of experimental accessible data using digital image correlation (DIC). The displacement field on the specimen surface is determined by deformation field measurement. The method has been used to evaluate the true stress-strain curve with a flat tensile specimen, which is normally used to determine the material properties in the material gradient. Materials stress-strain curves necessary as input for finite element analyses cannot be determined straight forward from global load versus elongation curves beyond the onset of necking after maximum load, as the strain field becomes inhomogeneous and the stress state triaxial. An analytical solution derived by Bridgman’s used for round tensile bars to determine the effective stress in the necked section. It requires the continuous measurement of the reduction of diameter and the necking radius during the test, which requires advanced testing techniques. Mostly, optical methods are applied. The specimen shape is photographed and the images are either evaluated manually or by electronic processing. The strain gradients in the cross section increase with the aspect ratio of rectangular bars. Difficulties also arise with the experimental determination of the cross section area. It cannot be evaluated from photos as the rectangular cross section takes the shape of a cushion, some procedures determining stress-strain curves from specimens with rectangular cross sections have been proposed in some study based on an extrapolation of the stress-strain curve before necking und thus not suitable for calculations with very high strains. The method uses the local thickness reduction in the necking area to determine the actual cross section area, but the triaxiality of the stress state after occurrence of local necking is not taken into account. The present methods of flat tensile specimens are favorably used for characterizing sheet metals. In these applications, standard round tensile bars cannot be used. Flat specimens can be tested in such cases instead. The determination of the true stress would additionally require a finite element simulation of the test. However, an approximate formula can be derived from numerical parameter studies which relate true stresses and applied load.

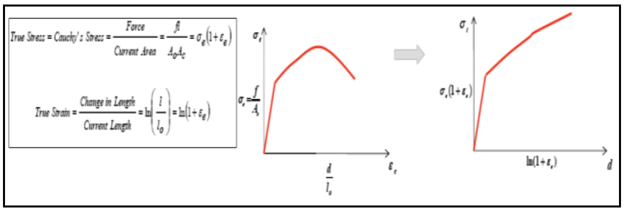
Fig.6 Tested standard specimen

A. Following is the typical procedure to convert material data to crash application

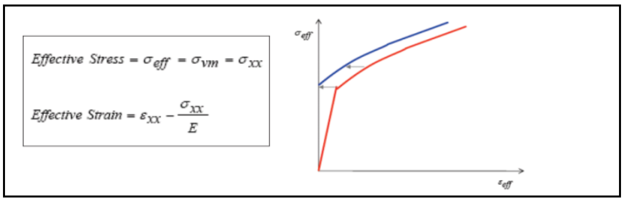
1) Standard coupons prepared for Uniaxial tension test to get Force-Deflection data
2) Force-deflection curve data is converted in engineering stress strain curve as follows-



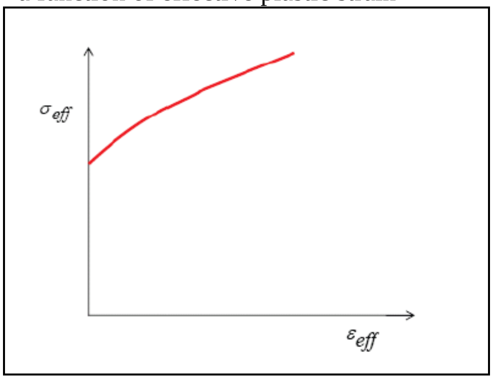
3) Engineering stress strain curve converted in True stress strain curve as follows



4) True stress strain curve is converted to effective Stress- Strain curve by removing the elastic strains as follows-

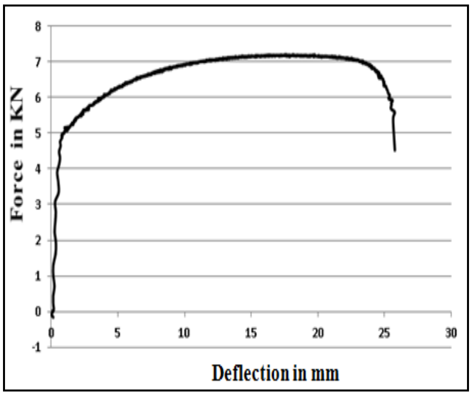


5) Resulting hardening curves relate the yield stress as a function of effective plastic strain-

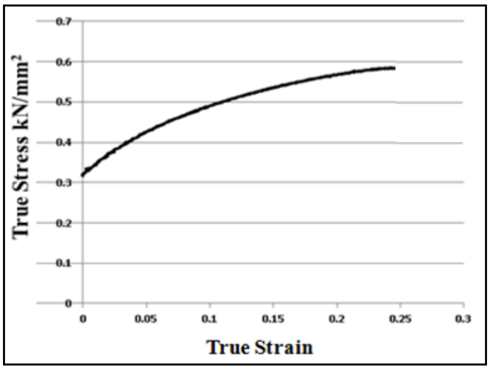


B. Input effective True stress-strain curve of steel materials to crash simulation (LS-DYNA)

Below fig 7 typical Force vs Deflection curve which we got from the slow strain rate (Quasistatic) and then it converted in to effective stress-strain curve which input for crash simulations.



(a) Output curve from test Force vs Deflection



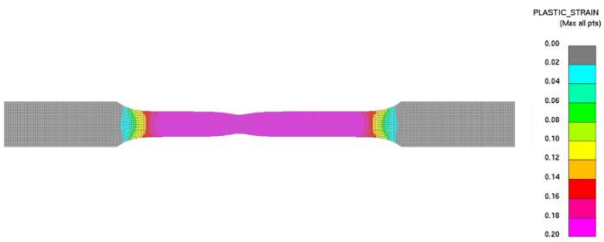
(b) LS-Dyna Input curve effective stress-strain

Fig.7 Input True Stress-Strain curve

C. Validation of Input effective stress-strain curve

As above section we converted the Force vs Deflection curve in to effective stress-strain curve which directlyuse for crash simulation. But again we need to validate this material curve in CAE. For this created FE model shown fig. 8 for the specimen same as tested on strain rate machine and applied boundary condition.For this simulation created two different FE model as per physical test i.e. one for slow strain rate and second one for high strain rate.

(a) FE model (specimen) for slow strain rate



(b) CAE results (specimen) for slow strain rate

Fig. 8 FE model (specimen) for slow strain rate

In the component simulation compare the Force vs Displacement CAE output curve with the physical tested Force vs Displacement curve and these two curves should be good correlates each other. This is the component level correlation for slow strain rate i.e. quasistatic testing. If not able to get good correlation in FD curve between test and CAE then we need to look on the input material effective stress –strain curve again and interpolate the material (hardening) curve in such way that we will get the good correlation. After interpolating the input material curve still not able to get the good correlation then we need to check the CAE input parameter i.e. mesh size, loading rate and material properties i.e. Young’s modulus. Below fig. 9 shown the comparison of FD curve between test and CAE and shown good correlation. Test curve in black and CAE curve in red color and shown good correlation up to the UTS. As this material is using for the crash application so we have concentrated only the plastic part of the material i.e. yield strength to UTS. If we observed the below correlation graph between Test and CAE the testing curve drop suddenly as compare to the CAE because of suddenly crack on the specimen. To incorporate this scenario in the CAE then needs to do the damage modeling for this particular steel grade material.

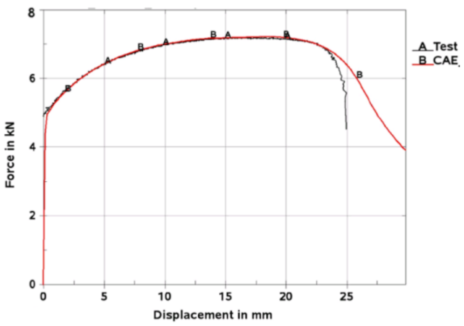


Fig. 9 Comparision of Force vs Displacement curve (Test and CAE)

As above paragraph we explained the correlation for slow strain rate i.e. Quasistatic loading. But it is very dificult to correlates the component level simulation for high strain rate material testing as the load is applying suddenly (applied velocity). Below fig. 10 shown the FE model for high strain rate.

(a) FE model (specimen) high strain rate

(b) CAE results (specimen) high strain rate

Fig.10 FE model (specimen) high strain rate

D. Material Models for Strain Rate Sensitivity

Currently, the most commonly used approach to modeling strain-rate sensitivity in progressive crushing is to use isotropic plasticity models with a rate sensitivity component that has moderate requirements on the experimental program. The models that are frequently used for crush simulations are the Johnson-Cook model, the Zerilli-Armstrong model and the piecewise linear plasticity strain rate sensitive material model. The models are appealing because they have been implemented in commercial codes used for crash simulations and have a limited number of material parameters that must be determined by experiments [6]. Experimental results for mild and HSS show that the strain hardening rate decreases with an increase in strain rate, and the case of constant hardening rate can be viewed as a limiting case. The material parameters can be selected such that strain hardening variations are insignificant.The most commonly used strain rate dependent material model in automotive engineering practice is the piecewise linear plasticity model. The model was used in this study because of its relevance to automotive crash modeling and flexibility for representation of strain rate sensitivity. In this approach, effective strain-stress curves are directly fed into the material models and require the least amount of effort for material model development. In simulations, for a given rate of strain (total or plastic), the resulting stress in the plastic region is linearly interpolated between the stress-strain values that were experimentally determined in strain rate tests [3]. The highest strain rate in the experimental data acts as a saturation plateau for strain rate effects. Important aspects of implementation of the piecewise linear plasticity model are the maximum strain rate for which the stress-strain data should be tested, and the number and arrangement of curves across the strain rate range.The material model uses linear interpolation between the curves whereas it has been shown that the stress increment relation is logarithmic. In the case when sufficient experimental data is available, the effects of linear interpolation should not be significant. Adding logarithmically interpolated curves improves the model accuracy when experimental data is not available for the intermediate strain rates.

Crashworthiness simulations are almost exclusively done using FEM programs with explicit time integration. The explicit time integration algorithms are only conditionally stable, which means that the integration time step must be smaller than the time for a disturbance to travel across the smallest finite element in the model [2]. For example, for steel and a finite element characteristic length of 5mm, this condition requires that the time step be smaller than 1 microsecond. The material constitutive relations and strain rates are calculated at this smallest time scale where wave propagation affects are important. The experimental data are determined on the higher time scales where the wave effects are not measured except for the experiments with highest rates. Therefore, it is important to determine the values of the strain rates in the explicit time integration calculations in order to define the extent of the required material experimental characterization program. It is also important to investigate the effects of FEM formulations and element discretization on magnitudes and distribution of plastic strains and strain rates in the areas of large plastic deformations that determine the crush mode, since these can then be correlated to the tube crush experiments. The simulations show the clear dependence of the strain rate calculations on the element discretization. Characteristic plastic strains and plastic strain rates for different element discretization at the time of formation of the second fold.

E. Strain hardening relation

Strain hardening is described using an extended Bergström relation [8]. To the original Bergström relation, the effect of strain rate and temperature are added as well as an improved behavior at high levels of strain. This results into the following relationship for the flow stress as a function of strain, strain rate and temperature.

$$\sigma_y(\bar{\varepsilon}) = \sigma_0 + \Delta\sigma_m \cdot \left[\beta \cdot (\bar{\varepsilon}+\varepsilon_0) + \left\{1 - e^{-\Omega(\bar{\varepsilon}+\varepsilon_0)}\right\}^{n'}\right] + \sigma_0^* \cdot \left[1 + \frac{kT}{\Delta G_0} \cdot \ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]^{m'}$$

σ0 = static yield stress
Δσm = stress increase parameter for strain hardening
Β = strain hardening parameter for large strain behavior
Ω= strain hardening parameter for small strain behavior
ε0 = pre-deformation parameter
n’ = exponent for the strain hardening behavior
σ^*_0 = limit dynamic flow stress
ΔG0 = maximum activation enthalpy,
m' = power for the strain rate behavior
k = Boltzmann constant = 8.617.10-5 eV/K
T = absolute temperature in (K)
ε& 0 = limit strain rate for thermal activated movement

As this equation also contains the temperature, the temperature increase seen in the tensile tests can be accounted for. Instead of providing measured temperature changes to equation values that were calculated using the simple temperature calculation model presented. As this all test are done at room temperature and temperature changes with respect to specimen is very small so we have neglected it.

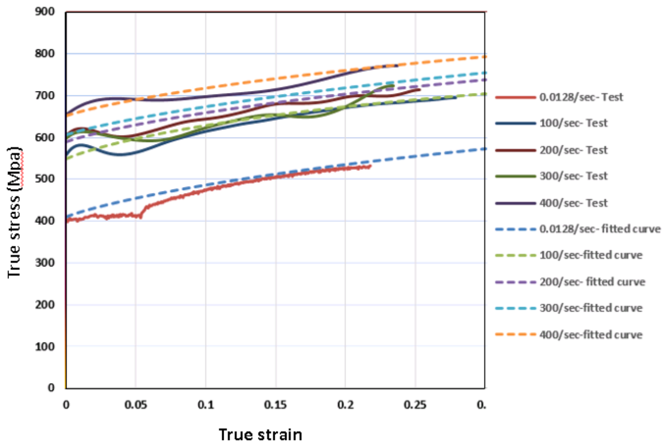


Fig.11 Effective stress-strain curve (Hardening curve)

F. Material Models

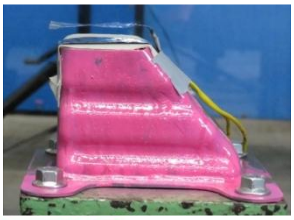
The implementation of strain rate effects of material models used in LS-DYNA [16] can be fulfilled in a variety of different ways. Besides a table like input of piecewise linear stress strain curves for different strain rates, a choice of different constitutive equations is available. The choice of these constitutive equations and the determined constants affect the ability to accurately predict the behavior of the steel components during the crash event. Five different models for strain hardening and strain-rate hardening are presented. As a Piecewise Linear Plasticity are based on mathematical formulations of the work hardening and strain rate sensitivity. From a mathematical point of view, they are a multiplicative type of equation. Thus, the calculated stress-strain curves at different strain rates are divergent. The calculated stress strain at different strain rates therefore is parallel.

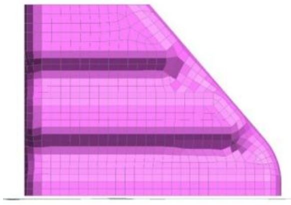
Piecewise Linear Plasticity material model the most commonly used strain rate dependent material model in automotive impact engineering is the piecewise linear plasticity model. In this approach, effective strain-stress curves are directly fed into the material model. Therefore, it requires the least amount of effort for the material model development. In LS-DYNA, a table is used to define for each strain rate value a load curve ID that gives the stress versus effective plastic strain for the rate. The lowest strain rate given in the table is applied if the strain rate falls below that minimum value. Likewise, the highest strain rate of the experimental data issued as a saturation plateau for the strain rate effects. In the simulation, the strain rate for each element is calculated and a linear interpolation between the experimentally determined strain rates is utilized to calculate the resulting stress in the plastic region. Even though it has been shown that the stress increment relation is logarithmic, the effects of the linear interpolation will not be significant, if the gradation between the different strain rates is sufficiently low. Fig.11 show the stress-strain relation that is fit to raw data Material validation for Dynamic loading (Crash Simulation):

The crash boxes are always subjected to dynamic loading in a real world collision. The impact speed adopted in the design of crash boxes is usually within the range of low to medium velocity of less than 20m/s. Although dynamic analysis has also shown a similar trend. To demonstrate the performance of the original crash box subjected to dynamic loading, the crushed configurations of model under dynamic loading of 7.8 m/s initial velocity is shown in Fig.12 as an example. The dynamic analysis to take material strain rate effect into consideration.

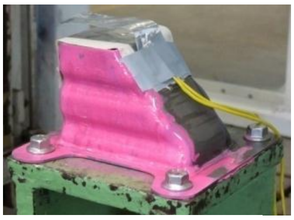
IV. COMPONENT TEST & SIMULATION

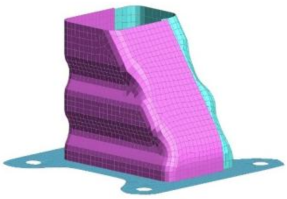
In this study, high strain rate tested material were selected for drop tower experiments in order to investigate the accuracy of the constitutive models based on piecewise linear plasticity model and various modeling approaches. The tests were modeled before the actual physical experiments to determine the test parameters. A test configuration for the steel crush box and the final deformed shape are shown in Figures 15. The crush box thickness of 2.5 mm and the length of 80 mm were welded to the base plate, which was bolted to the test fixture, and the drop weight of 150 kg impacts the tube at 7.8 m/s. Force, accelerations, and high-speed photographs were recorded during the experiments. There were a total three sets of small crush assemblies used in this study. There were three repeated tests with same configuration. In order to make the component test more stable and obtain more consistent deformation modes, the components were bolted to a plate on fixture,





Test Specimen CAE FE model





Test Specimen CAE FE model

Fig.12 Component for test and CAE

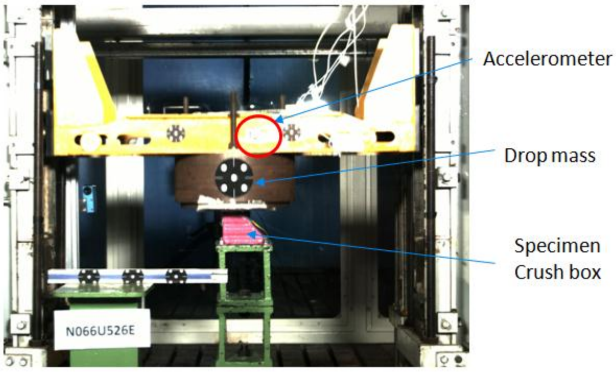


Fig.13 Component drop rig test Setup

A. *Finite Element Analysis*

A typical component test setup in CAE analysis is shown in fig.14. Finite element analysis of the crush box impacted by the 150 Kg mass and 7.8 m/sec was performed using finite element code LS-Dyna V 6.0 [16]. Several finite element models, with element sizes of 4-5 mm, were constructed. An optimum mesh size was determined by comparing the analysis results from the various finite element models. Comparison of mean force, maximum deflection and deformation mode predicted by the finite element analyses are to the experimental data was used to make the optimum mesh size determination. The accuracy of the remaining elasto-plastic materials curve fitting options and the material model were evaluated using the 4-5 mm mesh as they were qualitatively better than 9mm mesh. Several factors affect the strain rate calculation in a finite element analysis. These factors include element size, material models, frequency at which the time history is saved, pre-strain in a formed part, etc. While it is of interest to study all these factors, the focus of this report is to only investigate the effects of element size and material models on the strain rate.

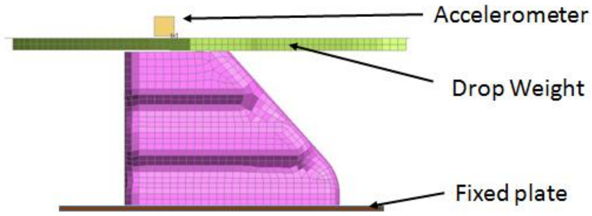


Fig.14 CAE Component test Setup

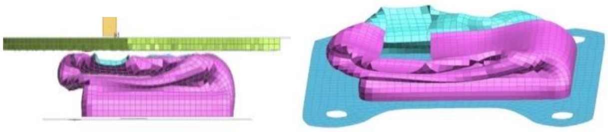
B. *Experimental results*

Deformation mode as crush can may deform in many different collapses modes. The mean crushing force associated with extensional mode is considerably higher than that of the in extensional mode. Therefore, the first thing before discussing the energy absorption capacity is to determine what mode will be developed when the corner regions of the crush can are strengthened. The deformation process of all specimens is shown in Fig 15. The deformed shapes of the crush can at the crushing distance shown in fig. 15 (c) and (d). It can be found that all specimens with both distributions deform in extensional mode. The initial fold of the crush can is found to be developed at a same distance along the length direction. Most of them are initiated in the top part of the crush can. Almost all crush can deform regularly fold by folding in extension al mode, the detailed figures of the deformed shapes of the specimen as shown fig. 15 (b). As below shown fig 15 (b) and (d) shown the deformation pattern observed in CAE almost same as compared with all repeated test.

(a) Initial condition of the three test specimen

(b) Deformation mode of three repeated tested specimen at end of test

(c) Deformation mode of three repeated tested specimen at end of test



(d) Deformation mode of CAE at end of test

Fig.15: Crush mode comparison of CAE and test

The comparison of the force vs. crush displacement between CAE and test is shown in Fig.16.

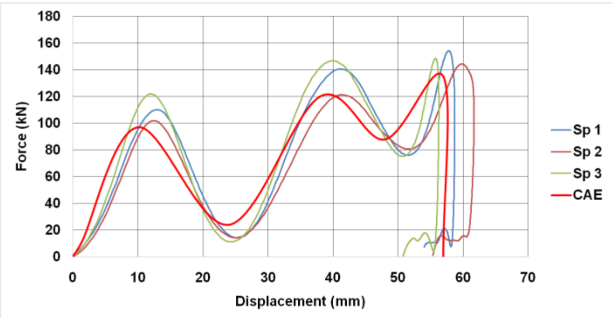


Fig. 16: comparison force vs. crush displacement Test and CAE

The peak values and timing match reasonably between the test and simulation. The force–crushing distance curves of the tested specimens are given. It can be found that the force response curves of the specimens show typical characteristics as those of under axial compression. However, the fluctuation of the curves for crush can with graded thickness is significantly different from those of crush can with constant thickness.

When material is deformed by external loading, energy is stored internally throughout its volume; Internal energy is also referred to as strain energy.Strain Energy of the member is defined as the internal work done in defaming the body by the action of externally applied forces. This energy in elastic bodies is known as elastic strain energy Strain energy is released when the constituent atoms are allowed to rearrange themselves in a chemical reaction interference are reduced. The external work done on an elastic member in causing it to distort from its unstressed state is transformed into strain energy.The strain energy in the form of elastic deformation is mostly recoverable in the form of mechanical work.

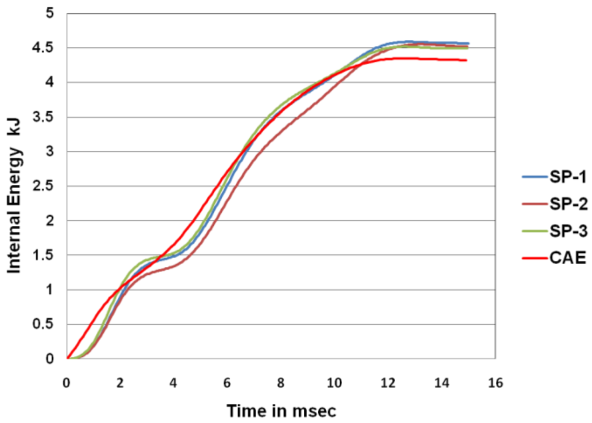


Fig. 17: comparison Internal Energy vs Time Test and CAE

Crash analysis is done to find the deformation, stress and energy absorbing capacity of various structural components of a vehicle hitting a stationary or moving object. The component is said to be crash worthy if it meets the plastic strain and energy targets. Crash analysis is also performed and If provide appropriate safety levels for impact vehicles occupants, the front structure designed to absorb as much impact energy as possible through its deformation and at the same time maintain its integrity. Meanwhile, the part of the impact of energy absorption of the current crush can component discussed in this paper. In addition to that, the comparison between the experimental results about the impact of energy done and the simulation included. These values conclude that thethis steel material proposed in similar behavior during a drop rig test.

Above comparison fig.17of internal energy Test vs CAE shows that energy absorb in simulation closest to the repeated three tested crush can.

V.CONCLUSION

From the results presented so far, the following conclusions can be drawn; addition of strain rate in full vehicle crash analysis reduces the dynamic crush and yields results that are closer to the test dynamic crush. Therefore, new material and strain rate coefficients obtained from this study should be considered for crash analysis applications. Overall, higher fidelity correlation was achieved with the piecewise linear plasticity material model to capture the strain rate behavior of steel. Strain rate sensitivity is an important component of the material models and needs to be incorporated in the crashworthiness models. Developed methodology to validate the strain dependent material characterization of steel grade in to account of crashworthiness application. The viscoelastic option for material modeling provides more realistically feasible strain rate. For modeling details of crush can crushing, the FEM mesh discretization should be fine enough, as measured by the strain distribution

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