

Material Modelling of PVC for change in tensile properties with variation in Strain Rate

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Abstract - Design of plastic part is totally different in comparison to metal parts. PVC belongs to polymer whose modulus does not change with change in strain rate. Material modelling of such material can be done in LS-DYNA with MAT-24 model. During impact or crash simulation of polymer material modelling was first step to perform as material properties of polymer varies with change in strain rate of loading. Tensile testing with change in strain rate is carried out on PVC specimen and validation performed using LS-DYNA software. The linear fit of yield strength against log of strain rate was developed for PVC and refined material model was developed using modelling parameters.

Key Words: MAT24, LS-Dyna, Eyring equation, Hypermesh

1. INTRODUCTION

Polymer shows complex behaviour in comparison of metal parts under loading conditions. To account this behaviour in CAE package with available material model, material modelling of polymer is important [3]. Parts made of polymers were common in many systems of the home appliances and automobiles due to advantages polymer such as light in weight, easy to form complex shape, cost effective etc. The material selected for study is used for display lens in home appliances which have electronic components enclosed in it. To account non-linear behaviour of the material simple material models were defined in LS-DYNA [8]. During impact simulation selection of exact material model as per material behaviour is important [4]. Parts supporting electronic, electrical components and part of aesthetics assembly were subjected to impact load testing in home appliances [10]. Hence material modelling of selected material with change strain rate is required. Objectives of study as follows:-

- Verify effect of element form, element size and meshing type on simulation results.
- To have equation for predicting change in yield strength as per change in strain rate of the material.
- Material modelling of the given material in LS-DYNA to account change in yield strength value with variation in strain rate of loading.

2. POLYMER (PVC) BEHAVIOUR

The polymer behavior cannot be categorized as totally nonlinear and hyper-elastic. The mechanical properties of plastic show variation with change in strain rate, change in temperature and other parameters. Most of plastic shows nonlinear elastic behaviour prior to yielding region. Trend of polymer response depends upon the type of polymer [5]. The behaviour of the PVC may be considered as analogues to steel in yielding region [2]. PVC shows reaching maximum stress beyond which it may undergo necking formation which cause strain hardening of material and sudden increase in stress value after showing yielding behaviour. The yield value of the PVC depends on strain rate and temperature. Due to increase in strain rate and decrease in temperature its value got more influenced.

In this paper, PVC is used for material modelling. The behaviour of the selected PVC is slightly different than normal PVC behaviour. It does not have abrupt stress increase in post yield region. Hence material modelling of it is quite difficult than other PVC. In general during simulation negatives slopes in stress-strain curve were mostly avoided [3].

3. MATERIAL MODELLING AND SPECIMEN PREPARATION

The material modelling starts with specimen preparation for tensile testing. For impact simulations it was essential to have material data with change in strain rate of testing. For fidelity of results obtained from experimentation ASTM standards needs to follow as per material. Figure.1 shows general flow chart to follow in material modelling procedure.

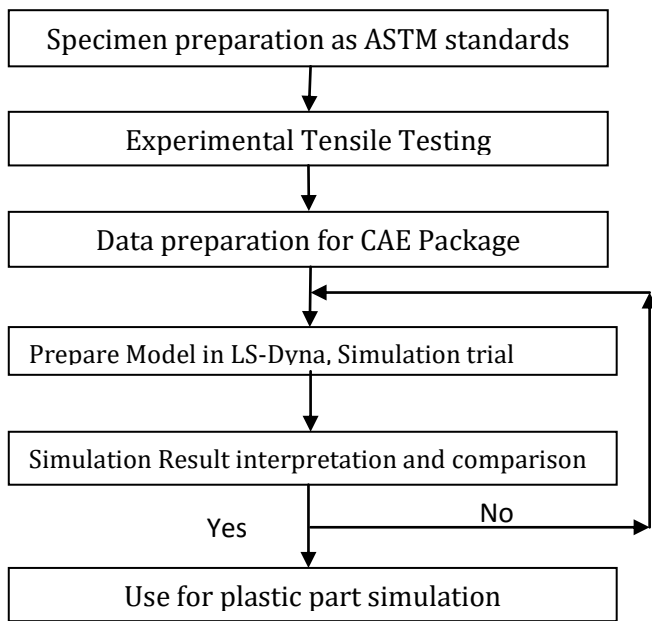


Figure.1: Flowchart for material Modelling

The main objective of material modelling is to replicate close behaviour of the any material under given loading condition. For good modelling purpose experimentation data with less noise data was important, Hence experimentation as per standards was important. The process starts with preparation of the specimen as per ASTM standards and carrying out the experimentation [7]. The data obtained from the test has been processed and Force-Deflection curve was generated which will be used for validation purpose. For creating material model which can account variation of strain rate in modelling, tensile test data with different strain rate was required. By using experimentation data material model parameters were calculated and processed for simulation validation. In Ls-Dyna for polymer materials generally linear elastic plastic model was used [4]. The simulations with different combinations will be repeated till close validation with Force-deflection curve was not established.

The specimen geometry for experimentation purpose was prepared as per ASTM D638 standard. The type of specimen used depends on thickness of material and its availability. The specimen has been cut from Injection moulded component. The variation in thickness of the specimen is within the tolerance limit as per standards. The shape of the specimen was dumbbell shape as shown in fig. 2.

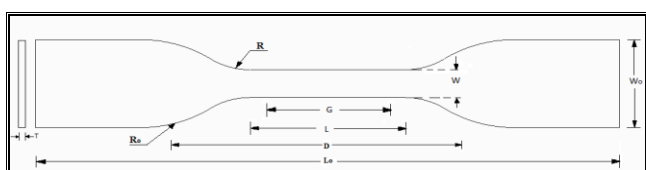


Figure 2: Tensile testing specimen

Table 1: Dimensions of the Specimen

Abbreviation	Description	units	Dimension s
G	Gage length	mm	25 ^{+0.13}
L	Length of Narrow section	mm	33 ^{± 0.5}
D	Distance between Grips	mm	65 ^{± 5}
Lo	Overall length of the specimen	mm	115
W	Width of the narrow section	mm	6 ^{± 0.5}
Wo	Width overall	mm	19+6.4
T	Thickness	mm	3 ^{+0.4}
Ro	Outer Radius	mm	25 ⁺¹
R	Radius of fillet	mm	14 ⁺¹

4. EXPERIMENTATION

The tensile testing was performed on Universal testing machine. The UTM was Advanced Computerized Electromechanical System machine. This machine consist of PC controlling system which works in close loop control for measuring parameters such as cross head stroke, loading force etc. The load cell used inside of machine has capacity of 10000N with least count of 0.1N force. Contact type high precision EX1 extensometer was used for displacement measurement.

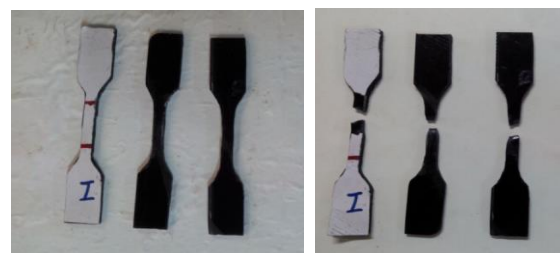


Figure 3: Tensile testing Specimen

The testing was carried out at different strain rates. Initially data of PVC for 50mm/min was collected by repeating same test number of times at same strain rate as per ASTM Standard. The curves obtained from these test helps to have smoothed material data available for modelling purpose. To account strain rate variable in model dumbbell shape specimen testing was carried out at 500mm/min, 50mm/min, and 10mm/min.



a. UTM Machine b. Extensometer Position

Figure 4: UTM machine and Extensometer Position

It was tough to measure data with accuracy at low strain rate less than 10mm/min. To ensure less noise in test results contact extensometer was used for strain measurement purpose. After that graphs obtained from these testing has been compared with graph obtained from 50mm/min results to check proper data collection and use average engineering stress-strain curve for modelling. The graphs obtained from testing were stress-strain graphs. By using numerical formulae's force Vs deflection curve and True Stress Vs True Strain curve was generated.

$$\text{True Stress} = \sigma / [(1 - \mu * \epsilon)^2]$$

$$\text{True strain} = \ln (1 + \epsilon)$$

Where, σ = Engineering Stress

ϵ = Engineering Strain

μ = Poisson's Ratio

σ_T = True Stress

The strain hardening curve has been derived from available stress strain curve results. This curve will be useful for use of LCSS option in Material modelling. If LCSS option was used then use of constants C,P which were related to Cowper-symond's equation will not be required. This option allows user to give no. of stress-strain curves as input to model. These curves were entered in the form of table which allows material model to interpolate stress-strain curve with change in strain rate.

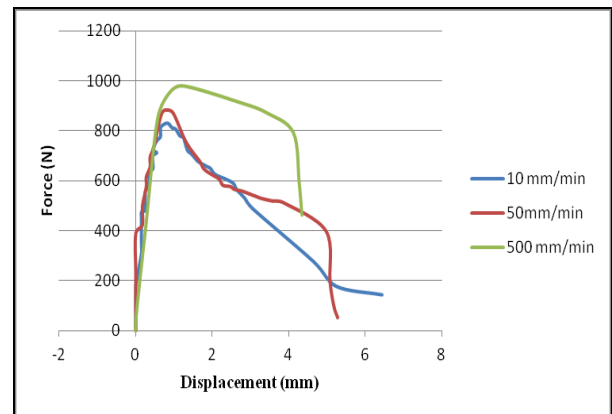


Figure 5: Engineering Stress-Strain curve with different strain rates

From testing following things were observed, with change in strain rate the mode of failure of the specimen changes. From stress-strain graphs for all tests it has been seen that the curve overlaps each other approximately in initial elastic region and it shows shift in yield point with progressive change in strain rate of testing. This behaviour of plastic shows that PVC belongs to polymer category whose modulus does not changes with change in strain rate, Hence Material model MAT24 of LS-Dyna can be used for its modelling purpose [4].The experimental results were influenced by noise factors involved in specimen preparation, experimentation facility and data collection system. The results obtained from the tensile testing can be plotted on log scale as shown in fig. 6

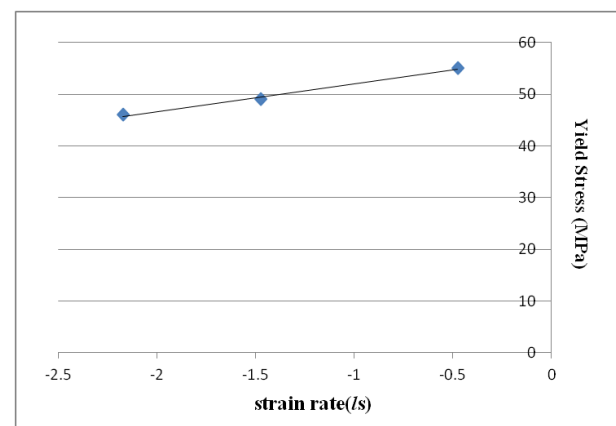


Figure 6: Plot of yield Stress Vs log on strain rate

The figure 6 shows change in yield value with respect to log of strain rate. This graph is helpful to predict the Eyring equation which helps to interpolate yield value as per change in strain rate. In CAE package to make use of LCSR option Eyring equation is helpful. Eyring equation predicts yield value shift more accurate compare to Cowper-symonds equation [3].From figure.6, equation giving close fit was found out, as follows: $Y = 57.36 + 5.3456 x$

5. SIMULATION

The validation process starts with checking the effect of variable options available within the software for modelling of the specimen. The variables were type of meshing, element form, and no. of elements along thickness of specimen etc. Making use of different type of mesh mainly depends on shape of the component. The accuracy of the results obtained with different meshing depends on element form used for particular meshing in LS-Dyna [6]. To check effect of element form, number of elements across thickness two simple simulations of plates with load at free end in cantilever condition and center load in fixed support conditions has been performed. These simulations show effect of element form and type of meshing on simulation results. From it element form with respect to type of meshing was decided and used in tensile testing simulation. From simulation and theoretical calculations it has been concluded that for HEX mesh 4 elements across thickness and element form 1 gives good co-relation with analytical result. R-TRIA Mesh shows more stiffness than TRIA mesh elements. Hence use of R-TRIA will give under-predicted results. TRIA mesh with element form 13 shows good co-relation. For this simulation trial PVC material was used. For simulation with polymer, linear elastic plastic model was used. Within these types of models MAT24 was most popular model used for simulation. MAT24 has ability to treat material in bi-linear manner which differentiate its behaviour in pre yield and post yield region. Using stress-strain curve obtained from testing true stress strain curve and its modulus was found out. The pre-processing was completed in HYPERMESH software and model solved in LS-Dyna.

By making use of results obtained from element analysis element form 13 was used as meshing was done with TETRA mesh. Total numbers of elements were 41638 and the nodes were 10336. Due to more number of elements it requires more time for solution. Boundary conditions has to replicate exactly same as Experiment. The left side of specimen was rigidly fixed while on right gripping portion cross-head speed was applied.

First simulation was carried out to decide modulus value for the material model. From results it has been seen with $E=3000\text{MPa}$ shows over prediction of results whereas $E=2500\text{MPa}$ will give under prediction of results. Hence $E=2800\text{MPa}$ has been selected which gives approximately same result as experimental curve.

To model post yield region LCSS option was available. By defining stress-plastic strain curve post yield region can be formulate. The limitation with PVC was LCSS option will not account negative slope curve [3]. To predict the post yield behaviour of the material tangent modulus option was used. The other variable which affect the modelling results were vp setting. Hence simulation using different vp setting was

carried out to select parameter predicting close experimental results. The effect of vp setting with 0 and 1 shows some variation but with vp setting 1 and -1 it gives same result.

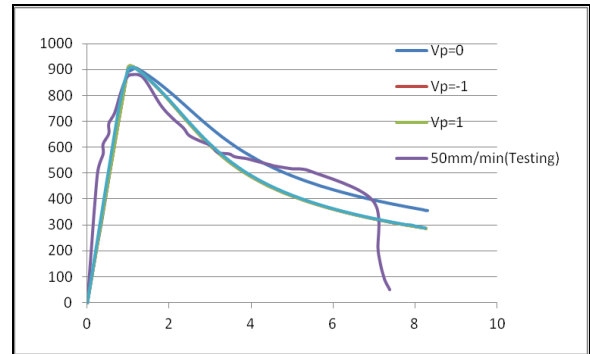


Figure 7: Force-displacement curve with vp in LS-Dyna

The reason for less predominant effect of vp setting was use of tangent modulus option. During these simulation trials point need to consider is correct application of boundary conditions. The nodes of specimen at moving ends were constrained in Y and Z directions else it shows wrong behaviour of specimen. The change in portion of fixing and moving elements changes the position of failure in simulation results. To check effect of poisson's ratio on results same simulations were performed with change in its value. It shows increase in maximum force value. To account for shift in yield point of the plastic with change in strain rate LCSR option was used. This option helps to provide ratios of yield stress vs strain rate inside the material card. After selecting vp setting as 1 simulation trials with change in strain rate was carried out. The graphs obtained from simulation were compared with experimental results.

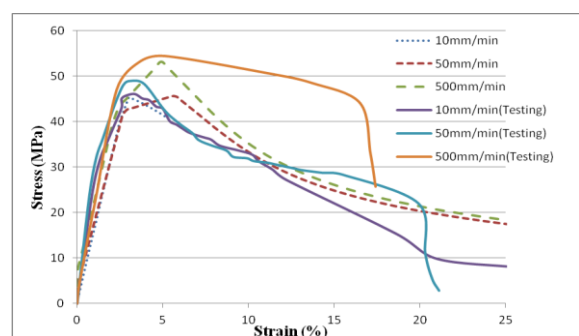
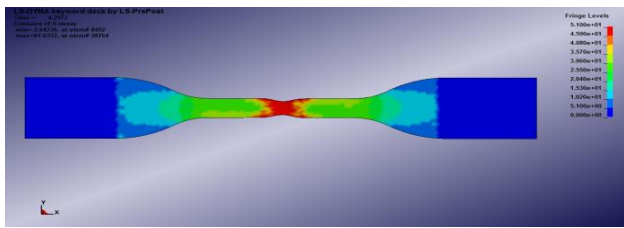


Figure 8: Stress-Strain curve

The simulation result shows close resemblance with experimental results till yielding region. Simulation with MAT24 shows necking phenomenon which was not seen in testing at all strain rates, as shown in figure 9 (b)



(a) CAE specimen failure



(b) Experimental specimen failure

Figure 9: Specimen failure

6. CONCLUSIONS

The material modelling helps to understand effect of different variables on reliability of results obtained from simulation. We can conclude that,

1. Type of element form used has more influence on simulation results for LS-DYNA. In lower order elements TYPE (13) for TRIA mesh and TYPE (1) for HEX mesh will be recommended.
2. The equation obtained from fig.6 allows interpolating yield stress analytically with change in strain rate within range of strain rate. Noise factors involved in experimentation, specimen preparation, part manufacturing etc. gives variation in results obtained.
3. The refined MAT24 model predicts approximately good results up to yield point. At high strain rate simulation shows non-linear shift prior to yield point if compared with actual result due to necking phenomenon in simulation and change in tangent modulus at same time.
4. The MAT24 can't account for change in shape of curve in post-yield region. Failure strain variation with change in strain rate can't be accounted by MAT24.

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