Manuscript received June 2, 2007; revised Sep. 19, 2007

# Thickness and Material Yield Strength Effects of Thin Sheets on Dent Resistance

JAVAD MARZBANRAD
Automotive Engineering Department,
Iran University of Science and Technology,
Narmak, 16846-13114, Tehran,
IRAN
marzban@iust.ac.ir

*Abstract:* - In this paper, dent resistance with static loading on a circular sheet is studied using finite element method. The effects of thickness and material strength are considered using simulated model for the sheet and for the loaded applied. Dent resistance is a quality criterion for automotive body panels which should be considered in design. It depends on material strength, thickness, panel geometry/shape. Due to the complexity of the problem, the verification of dent resistance of body panels is often done after the panels are formed and assembled. A computer simulation technique was developed here for dent resistance prediction, which can potentially be used in early design stages before panels are produced. Simulation techniques are discussed using implicit (FEA) for denting simulation. The attentions are focused on correlation of computer simulation and then compared with some experimental results for verification. The results show the reasonable prediction for dent resistance obtained from computer simulations. A circular panel used here and its dent resistance is calculated at the centre. The test data from experimental results are also presented here to be compared with the results of FEA model.

*Key-Words*: - Dent, Resistance, Sheet, Thickness, Yield strength

## 1 Introduction

Today's Emissions and energy problems cause automotive industry try to reduce automotive weight. A significant weight reduction would be realized by substituting thinner high strength steel or thicker aluminium alloys for outer body panels of conventional material. However weight reduction by sheet material substitution cannot carry out at the expense of deteriorated panel properties. For exterior panel, dent resistance is essential quality measure. Static dent resistance is a measure of the panels resistance to plastic deformation caused during handling (both manufacturing and service stations), at parking lots and by hands and elbows and so on.

Campbell [1] and Seel [2] defined dent as visual surface deformation, the value of strain at the upper limit of the elastic region according to Yutori et al. [3], or specified deformed depth at a given load like the work of Shah [4], Dicello [5] and Painter et al. [6]. Correlations established indicate that dent resistance is a function of panel yield strength and sheet thickness as stated by Burley [7] and Ming et al. [8], in which thickness is often raised to a power and takes panel curvature account.

Since the dent resistance test is performed in late stages of the panel design cycle, any failure in dent testing involve tremendous rework in both design and manufacturing. It is often very costly and time consuming to correct the problem. Recently, prediction of denting behaviours using computer simulation in early design stages has brought significant interest mainly because of advancement in computer simulation technology and cost saving potential. The finite element analysis (FEA) is widely used in vehicle structural design and process simulation. Some early simulation work was also conduct for denting applications like Raghavan and Arwashan [9], Alaniz et al. [10], Werner [11] and Sabbagh [12] and Diconsanzo et al. [13]. Holmberg and Thilderkvist [14] investigated the influence of material properties and stamping conditions on static dent resistance of automotive panels. Jung and Worswick [15] presented a parametric study for static and dynamic denting. Deolgaonkar and Nandedkar [16] analyzed recently the non-linear transient dynamic dent resistance of auto body panel using Ansys-Ls Dyna. Due to the complexity of denting problems, accurate analytical solutions are difficult to achieve.

In this paper, dent resistance on a circular sheet with 76.2 mm diameter is studied with computer simulation and compared with experimental test on sheet with 0.73 mm thickness.

The dent resistance varied from point to point on a panel. In this investigation, the attention is focused on the dent resistance at only in the centre of panel and measured. The effect of thickness and strength of material is studied here following the test procedure with the finite element method using Ansys-Ls Dyna.

## 2 Material

A CABH (Continuous annealed bake hardenable) steel sheet was selected for this study. The steel sheet stress-strain data is obtained by tensile test. Test specimen with 0.73 mm thickness is used for tensile test.

For using the material specification of panel, material engineering stress-engineering strain data should be converted to the true stress-true strain format. Figure 1 shows difference between CABH steel engineering and true data.

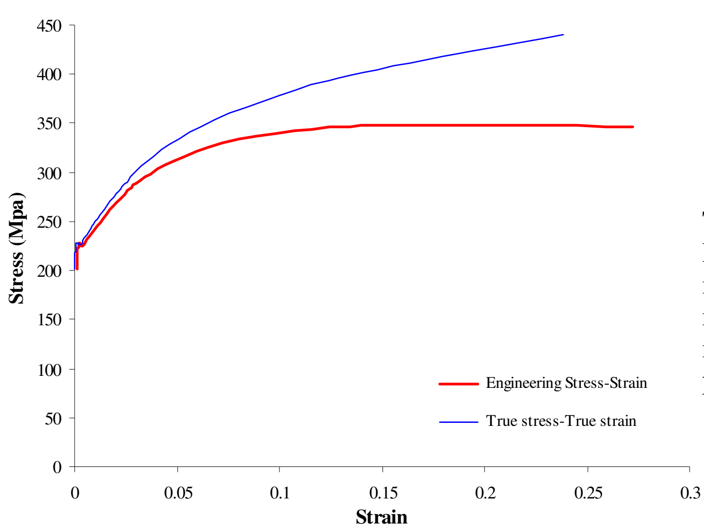


Fig. 1. CABH in the aged condition engineering and true stress-strain curve

HLSA 340-CR, HLSA 340-HGDI and HLSA 280-HDGI steel sheets true stress-strain curve are shown in Figure 2. The steel sheet can be ranked by material strength in following order.

HSLA340-HGDI>HLSA280-HGDI>CABH>HLSA340-CR (1)

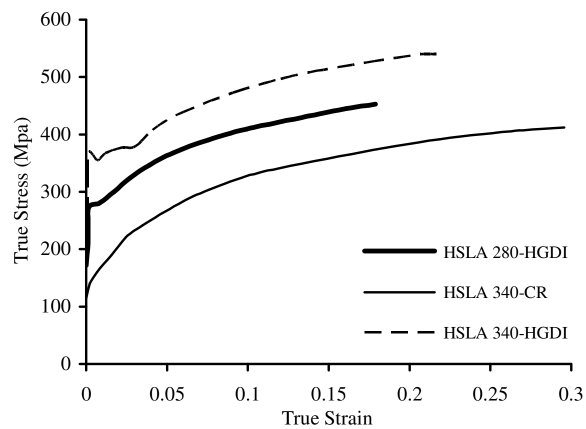


Fig. 2. Steel sheets true stress-strain

## 3 Denting simulation

### 3.2 Model simulation

Circular flat sheet with 76.2 mm diameter modelled for dent resistance simulation in LS-DYNA software. The model used here is shown in Figure 3.

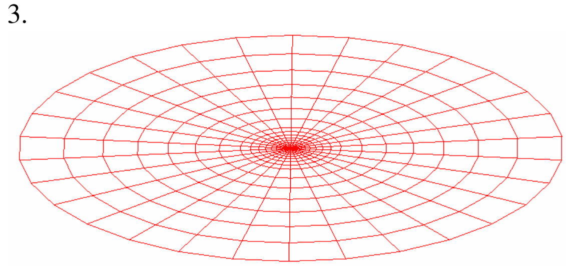

Fig. 3. Flat panel with 76.2 mm diameter

This circular sheet meshed by shell element with Belychesko-Tesy element formulation. Material model 24 (Mat-piecewise-linear-plasticity) and material model 20 (Mat-rigid) are used for panel material and punch material, respectively. The punch is also modelled as a hemispherical with 11.1 mm diameter as shown in Figure 4.

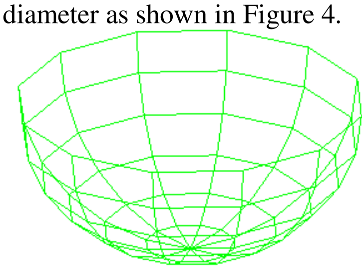

Fig. 4. Hemispherical punch with 11.1 mm diameter

### 3.3 Boundary condition

To evaluate the static dent resistance, the panel was first fixed in the outside circumference and applied incremental cyclic load at the panel centre with hemispherical punch. In Figure 5, one can observe this incremental cyclic load curve. The permanent deformation (dent depth) in the panel is measured at the panel centre. Loading is applied using hemispherical punch of an 11.1 mm diameter.

### 3.4 Dent simulation

Incremental cyclic load as shown in Figure 5 applied to hemispherical punch for dent simulation. The test is started with increased load from zero to an initial load, then decreasing the load to zero. In this way, the first cycle is completed and measured all displacement data in this cycle. This procedure is repeated for upper load cycle.

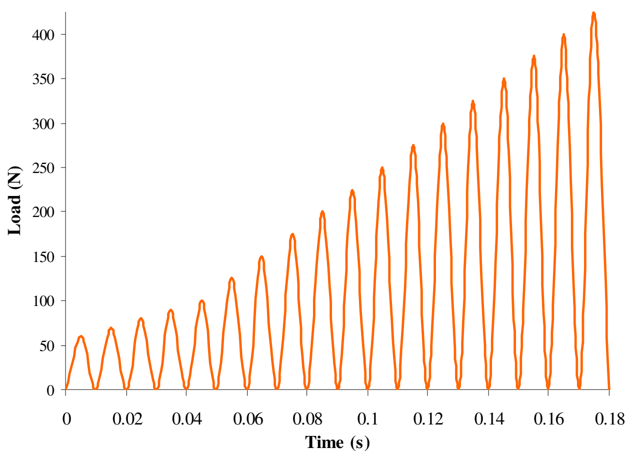


Fig. 5. Incremental cyclic load

Figure 6 shows the loading and unloading cycles' curve versus displacement of a panel with 0.73 mm thickness. As can be seen in Figure 6, points A and B are maximum load and residual displacement in last cycle, respectively. The data were then reduced to maximum load and residual displacement in each cycle with a computer code. Load-displacement data of Figure 6 were reduced to important data were shown in Figure 7. Each point in Figure 7 refers to dent depth in cycle with specific maximum load for both the simulation and the practical test.

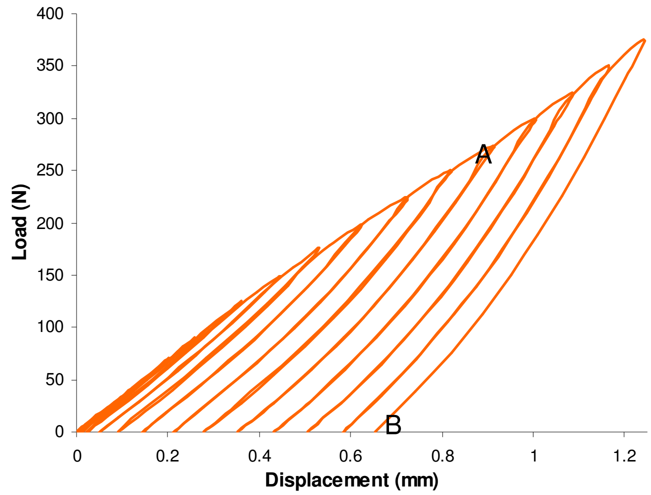


Fig. 6. Panel with 0.73 mm thickness load-displacement

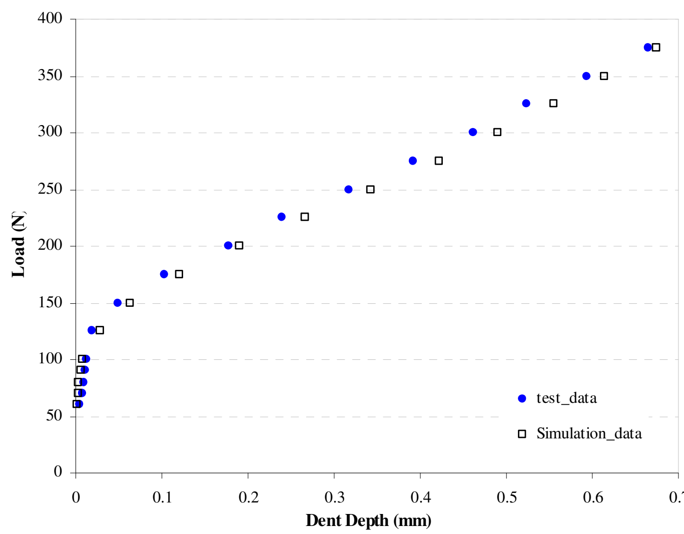


Fig. 7. CABH in the aged condition dent depth for 0.73 mm thickness sheet

### 3.5 Computer simulation verification

Figure 7 shows dent depth obtained from computer simulation for each maximum load in loading cycle. Results of computer simulation are provided with experimental dent resistance test data in this figure. It is concluded that the simulation method can be used for dent experimental tests with good accuracy.

Table 1. Results of Simulation and Yutori equation in 0.1 mm dent depth with Yutori modified parameter (a=2.04645 and $K_1$=1.42757)

| Sheet Thickness | $F_0$ Predicted by Simulation | $F_0$ Predicted by Yutori |
|---|---|---|
| 0.6 | 111.9181 | 111.9181 |
| 0.7 | 153.4276 | 153.4276 |
| 0.73 | 165.4465 | 167.1859 |
| 0.8 | 201.3196 | 201.6420 |
| 1 | 318.5032 | 318.3482 |

## 4 Thickness effect

Denting simulation is performed here using LS-DYNA implicit method on a circular sheet and the results are compared to the experimental data of Diconsanzo et al. [13]. This modelling is shown in Figurte 8. Then effect of thickness on dent resistance is investigated for this circular sheet with 0.6 to 1 mm thickness. Denting simulation is done for this range of thickness and results are recorded. Yutori [3] suggested experimental equation as follows:

$$F_0 = K_1 \sigma_Y t^a \quad (2)$$

where $F_0$ is the denting force require for 0.1 mm dent depth, $K_1$ is material constant, $\sigma_Y$ is yielding strength, t is the sheet thickness and a is geometric constant.

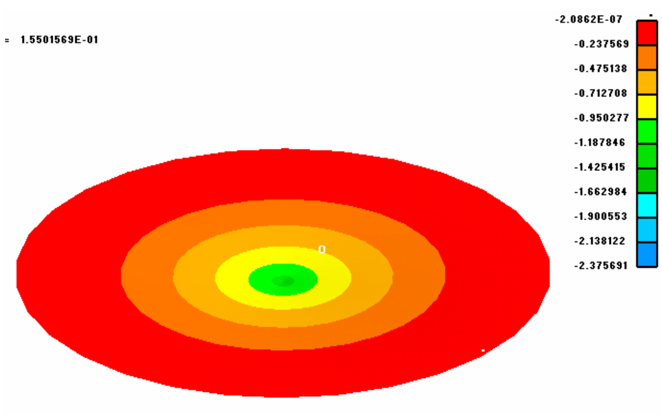


Fig. 8. Sheet deformation in maximum load

In Table 1, the result of simulation and Yutori empirical equation prediction data for number of thicknesses are compared. K1 and a, parameters in Yutori empirical equation for the specified material and geometry are calculated in circular sheet between 0.6 and 0.7 thickness. As can be observed, Yutori empirical results are very close to the computer simulation results.

Increasing the panel thickness causes increasing the panel dent resistance. Consider that if automotive exterior panel thickness decreases to reduce vehicle weight, then panel dent resistance decrease by the power of 2 or more.

## 5 Material strength effect

The effect of material strength on dent resistance is investigated for this circular sheet with HLSA 340-CR, HLSA 340-HGDI and HLSA 280-HDGI steel sheets. Denting simulation is done for this range of material and results are recorded and compared to the experimental data obtained by Diconsanzo [13]. In table 2 results of simulation and Yutori empirical equation prediction data for different yield strength are compared. K1 and a, parameter in Yutori empirical equation for the specified material and geometry are calculated in circular sheet are found. As can be seen, Yutori empirical equation predictions are approximately the same as computer simulation results.

Increase in panel yield strength cause the increase of panel dent resistance. Consider that if automotive exterior panel thickness decreases to reduce vehicle weight, then panel sheet material should be change to prevented distorted panel dent resistance property.

Table 2. Comparison between simulation and Yutori equation in 0.1 mm dent depth with Yutori modified parameter

| Yield strength (Mpa) | $F_0$ Predicted by Simulation(N) | $F_0$ Predicted by Yutori eq (N) |
|---|---|---|
| 137 | 95.9337 | 102.7106 |
| 221 | 162.6732 | 165.6865 |
| 223 | 165.4465 | 167.1859 |
| 261 | 223.0719 | 195.675 |

## 6 Conclusion

The dent resistance of thin sheet metal subjected to static or semi-static loading is studied here. According to the modelling of dent resistance for investigation of thickness and material strength effect of thin sheet metals, the following results may be drawn as:

- It is shown that the static dent resistance can be predicted using computer simulation. The predicted results agree well with experimental data.
- A fine mesh in denting area is required for accuracy of the simulation result. It is noted that a very fine mesh increases the time of calculation and does not improve the simulation accuracy.
- A complete stress-strain curve achieved from the tension test should be used in the denting simulation for good accuracy.
- Dent resistance decreases if panel thickness is reduced.
- Material strength has approximately direct effect on the dent resistance for circular flat sheet panel.
- Dent resistance decreases if the material strength reduces.
- Automotive Designers should consider dent resistance when they are interested in reducing the panel thickness in order to decrease the automotive weight.
- If dynamic loading is applied to sheet metal, some more investigation should be accomplished that are not done here. In this case, impact lading can be similar to the sand jumping from a tire of a car and hitting to a panel of another car. The author is interested to continue it in the future and separate research.

*References:*


[1] Campbell, M.P., Evaluation of continuous annealed bake hardenable steel for improved dent Resistance, SAE Paper No. 890711, SAE, Warenable, PA., 198.9.

[2] Seel T.N., *Bake hardening application study–key factors of dent resistance improvement*, SAE Paper No. 910291, SAE, Warenable, PA., 1991.

[3] Yutori, Y., Nomura, S., Kobubo, I. and Ishigaki, H., *Studies on the static dent resistance*, Proceedings of 11th IDDRG, Les Memoiries Scientifiques Revue Metallurgie, Mars, 1980, pp. 561-569.

[4] Shah, V.C. and Wenzloff, G.J., *A comparison of material, process and design optimization strategies to achieve dent resistance outer body panels*, Proceeding Proceedings of IBEC, Automotive Body Materials, 1994.

[5] Dicello, J.A. and George, R.A., *Design criteria for the dent resistance of auto body panels*, SAE Paper No. 740081, SAE, Warenable, PA., 1974.

[6] Painter, M.J. and Pearce, R*., The denting behaviour of some sheet materials,* Proceedings of 12th IDDRG, S Margherita Ligure, Italy, 1982, pp. 399-410.

[7] Burley, C.E., Niemeier, B.A. and Koch, G.P., *Dynamic denting of autobody panels*, SAE Paper No. 760165, SAE, Warenable, PA., 1976.

[8] Ming F., Meuleman, David J., Christine, L., Alaniz and Stephen J., Zurdosky, *An evaluation of automotive steels*, SAE Paper No. 910287, SAE, Warenable, PA., 1991.

[9] Raghavan, K.S. and Arwashan, Naji, *Analysis of Quasi-Static Denting Behaviour of Automotive Sheet Steels*, SAE Paper No. 970984, 1997.

[10] Alaniz, C.L., Brookes, L.E. and Seel, T.N., *Investigation of body panel stiffness as predicted by finite element analysis*, SAE Paper No. 900716, 1990.

[11] Werner, M.F., *Finite element simulation of steel body panel performance for Quasi-static dent resistance*, Proceedings of IBEC, Automotive Body Material, 1993.

[12] Sabbagh, M.A. and Chavali, R.N., *Quasi-static dent depth simulation using non-linear FEA*, Proceeding of IBEC, Automotive Body Material, 1995.

[13] Diconsanzo, G.P., Matlock D.K. and Foley, R.P., *Effect of tensile properties on dent Resistance of sheet steels*, SAE Paper No. 960024, SAE, Warenable, PA., 1996.

[14] Holmberg, S. and Thilderkvist, P., *Influence of material properties and stamping conditions on the stiffness and static dent resistance of automotive panels*, Journal of Materials and Design, 23 (8), 2002, pp. 681-691.

[15] Jung, D.-W. and Worswick, M.J., *A parameter study for static and dynamic denting,* KSME international Journal, 18 (11), 2004, pp. 2009-2020.

[16] Deolgaonkar, S.S. and Nandedkar, V.M., *Analysis of dynamic dent resistance of auto body panel*, AIP Conference Proceeding, 907, 2007, pp. 252-257.