GREAT DESIGNS IN STEEL

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GREAT DESIGNS IN STEEL

A PRACTICAL METHOD FOR MODELING FLCS OF 3RD GEN AHSS AT ROOM TEMPERATURE AND BORON STEEL AT HOT STAMPING TEMPERATURES

Steven Sheng

Sr. Process and Formability Engineer

Global Die Center, General Motors, Warren, MI, USA

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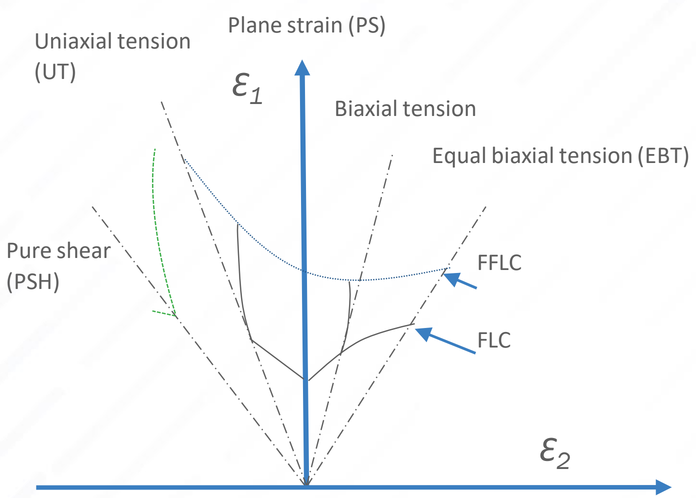
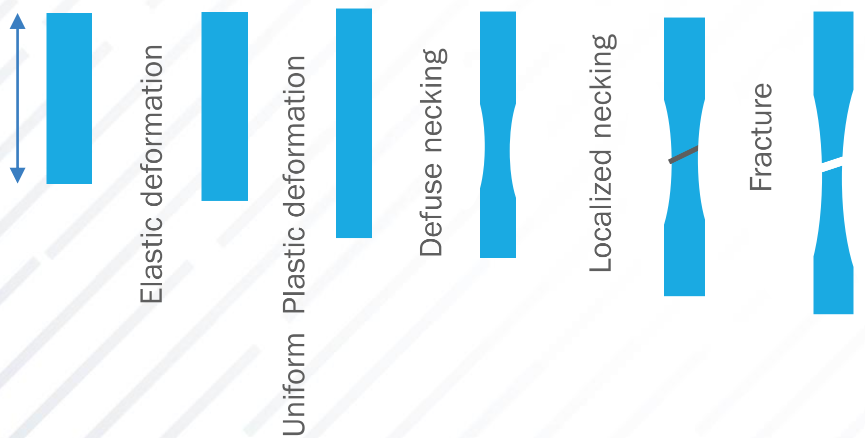
INTRODUCTION – DUCTILE FAILURE, FLC AND FLD



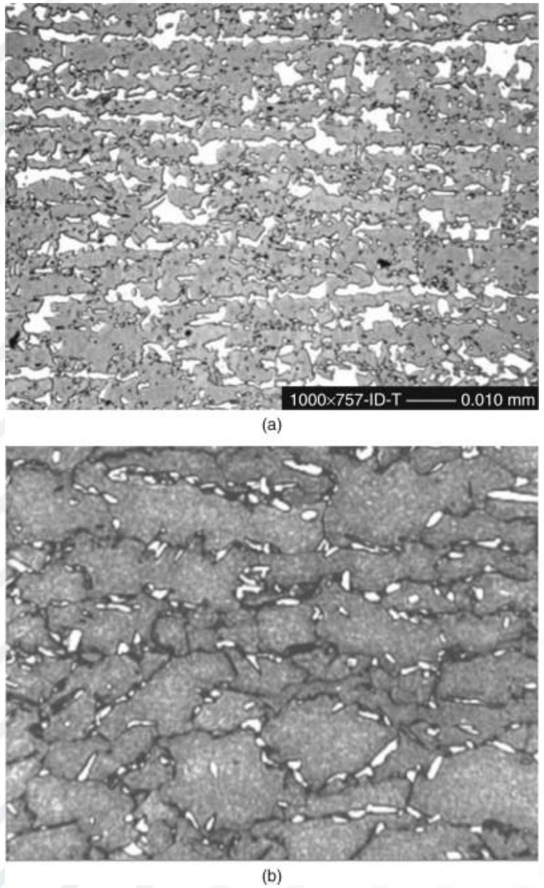
FLC, FFLC [li et al. 2010 IJPT]



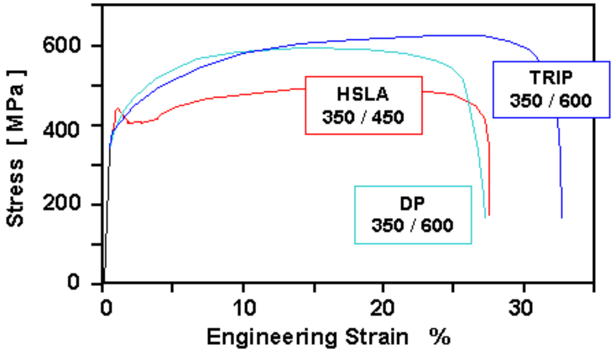
$$FLD_0 = \frac{n}{0.21}(23.3 + 14.1t), n < 0.21$$

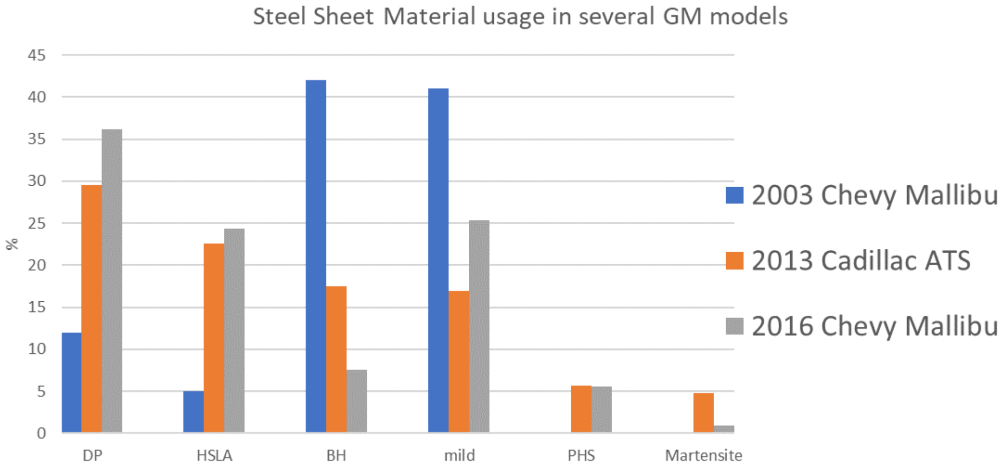
NADDRG Equation [Keeler, 1977]

INTRODUCTION – FLC & AHSS AT ROOM TEMPERATURE

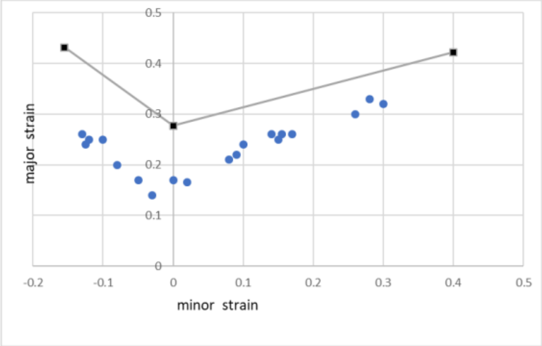


Microstructures of a) DP and b)TRIP steels [Tumuluru, 2006]



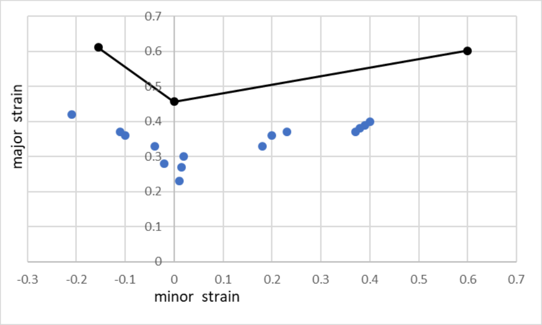


Application of DP steels in GM models [Fonstein 2017 Automotive Steels]



1 mm DP780

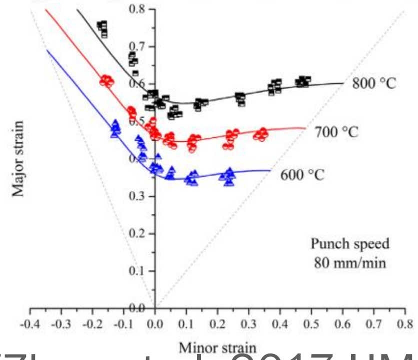
Experimental data from [Lou et al. 2012]



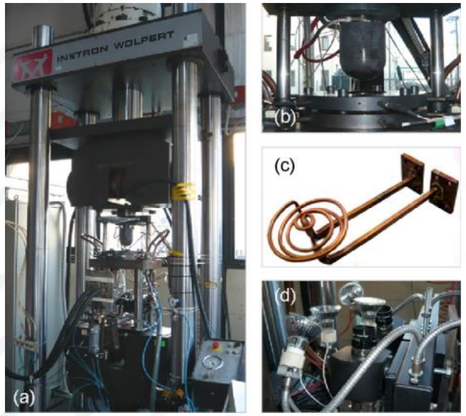
1.6 mm TRIP690

Experimental data from [Li et al. 2010]

INTRODUCTION – FLCS OF BORON STEEL AT HOT STAMPING TEMPERATURES



[Zhou et al. 2017 IJMS]



Dome test with temperature control [Bariani et al. CIRP 2008]

Table 1 A summary of several Nakajima tests on Boron steel

Source	T (°C)	Punch speed (mm/s)	Thickness (mm)	Sample width (mm)	Failure	Thermal condition
Bariani et al. 2008	600	10	1.5	n/a	Necking / fracture	Iso
Pellegrini et al. 2009	600	8.3 - 10	1.5, 1.75	n/a	Necking/ fracture	Iso
Min et al 2010	780-813	30	n/a	20-180	Marginal at fracture	Iso
Li et al. 2014	600-800	30	1.4,1.6,1.8	20-180	Fracture	Iso
Cui et al. 2015	400-900	10	1.5	20-180	Necking/ fracture [a]	Iso
Shi et al. 2016	600-800	n/a	2.0	20-180	Necking	Iso
Georgiadis et al. 2017	650	50	0.5, 0.8, 1.25	30-210	Fracture?	Non-iso
Zhou et al. 2017	600-800	0.667/1.334	2.0	20-180	Marginal and critical of necking	iso

[a]: the presented forming limits are assumed at necking due to the safety margin (20%) given relatively to limit strains at fracture

A DUCTILE FAILURE CRITERION

Critical damage is a function of strain path [Benzerga and Leblond 2010, Tasan et al.2009, Janilier and Schmitt 1982]

[McClintock 1968]

$$f(t_0,\rho)D_{cri}^{UT} = \int_0^{\bar{\varepsilon}^n}(\eta + \langle\psi\rangle\bar{\tau})d\bar{\varepsilon}$$

Thickness [Keeler and Brazier 1977, Raghavan 1995, Suh et al. 2010, Dilmec et al. 2013]

$$\psi = \begin{cases} 0, & \rho^{UT} < \rho \\ \frac{\rho^{UT}-\rho}{1+\rho^{UT}}, & -1 \le \rho \le \rho^{UT} \end{cases}$$

PSH -> UT

$$\bar{\tau} = \frac{\tau}{\bar{\sigma}}$$

η stress triaxiality, $\bar{\varepsilon}^n$ effective strain at localized necking, t_0 initial sheet thickness, ρ ratio of incremental minor strain to major strain, isotropic yielding, the critical damage in uniaxial tension

$$D_{cri}^{UT} = \frac{\varepsilon_1^n(t_0,-0.5)}{3}$$

[Sheng and Mallick 2017 IJMS, 2018 SAE IJMM]

AN IMPROVED ZENER-HOLLOMON PARAMETER

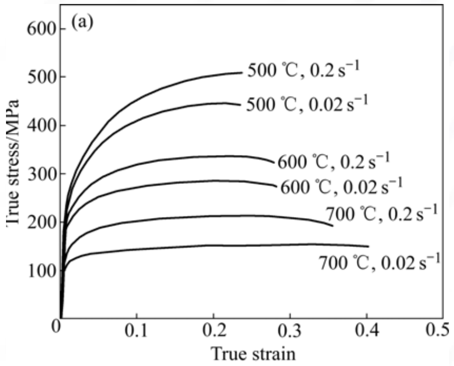
Exponential strain rate sensitivity factor s is introduced

$$Z' = \dot{\varepsilon}^s e^{Q/_{RT}}$$

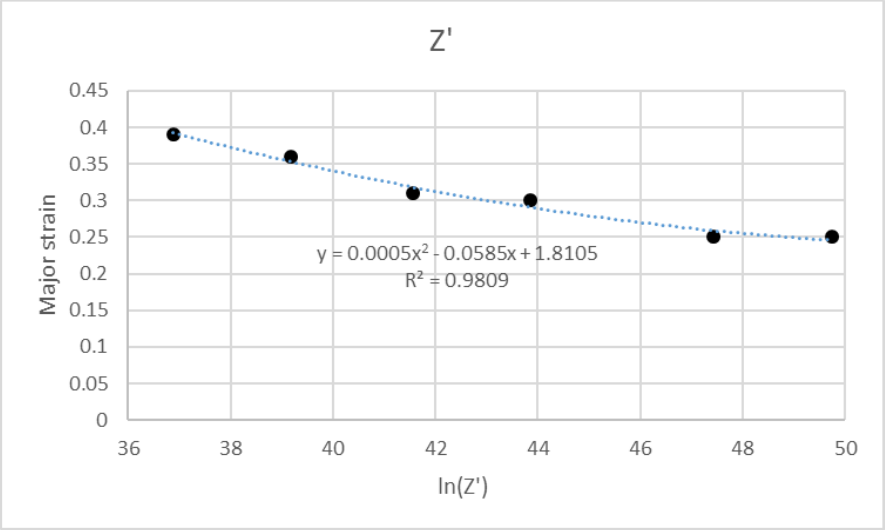
Q – activation energy;
R – gas constant;
T – absolute temperature
S – strain rate sensitivity factor

$$\varepsilon^n = A(ln(Z'))^2 + Bln(Z') + C$$

[Sheng 2017, Sheng and Mallick 2017 ASME JMSE]



[Jang et al. 2009]



$Z' - DFC$ AND PREDICTION OF FLCs

$$f(t_0,\rho)D_{cri}^{UT}(t_0,Z') = \int_0^{\bar{\varepsilon}^n(t_0,\rho,Z')} h(Z')\eta \, d\bar{\varepsilon}$$

Plane stress and linear strain path assumption, Major limit strain at UT, effect function at PS and EBT:

$$\begin{Bmatrix} \varepsilon_1^n(t_0,-0.5,Z') \\ g(t_0,\rho^{PS},Z') \\ g(t_0,\rho^{EBT},Z') \end{Bmatrix} = \begin{bmatrix} A^{UT} & B^{UT} & C^{UT} & D^{UT} & E^{UT} & F^{UT} \\ A^{PS} & B^{PS} & C^{PS} & D^{PS} & E^{PS} & F^{PS} \\ A^{EBT} & B^{EBT} & C^{EBT} & D^{EBT} & E^{EBT} & F^{EBT} \end{bmatrix} \begin{Bmatrix} (ln(Z'))^2 \\ lnZ' \\ 1 \\ t_0^2 \\ t_0 \\ (ln(Z'))t_0 \end{Bmatrix}$$

$$\varepsilon_1^n(t_0,\rho,Z') = \begin{cases} \varepsilon_1^n(t_0,0,Z') + (1.414\rho - 0.414\rho^2)\left(\varepsilon_1^n(t_0,1,Z') - \varepsilon_1^n(t_0,0,Z')\right), 0 < \rho \le 1 \\ \varepsilon_1^n(t_0,0,Z') - 2\rho\left(\varepsilon_1^n(t_0,-0.5,Z') - \varepsilon_1^n(t_0,0,Z')\right), -0.5 < \rho \le 0 \end{cases}$$

PREDICTION OF FLC AT ROOM TEMPERATURE

Major limit strain at UT, effect function at PS and EBT

$$\begin{Bmatrix} \varepsilon_1^n(t_0,-0.5) \\ g(t_0,\rho^{PS}) \\ g(t_0,\rho^{EBT}) \end{Bmatrix} = \begin{bmatrix} D_r^{UT} & E_r^{UT} & F_r^{UT} \\ D_r^{PS} & E_r^{PS} & F_r^{PS} \\ D_r^{EBT} & E_r^{EBT} & F_r^{EBT} \end{bmatrix} \begin{Bmatrix} t_0^2 \\ t_0 \\ 1 \end{Bmatrix}$$

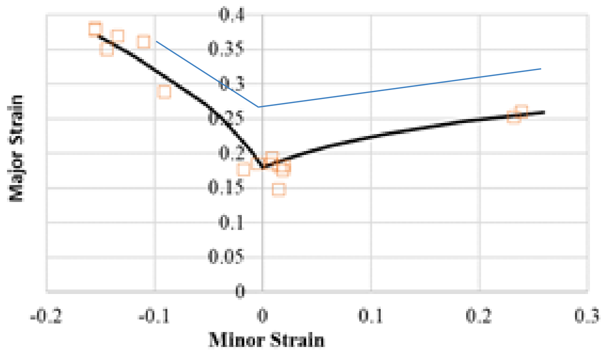
For one grade

$$\begin{Bmatrix} \varepsilon_1^n(t_0,-0.5,YS) \\ g(t_0,\rho^{PS},YS) \\ g(t_0,\rho^{EBT},YS) \end{Bmatrix} = \begin{bmatrix} A^{UT} & B^{UT} & C^{UT} & D^{UT} & E^{UT} & F^{UT} \\ A^{PS} & B^{PS} & C^{PS} & D^{PS} & E^{PS} & F^{PS} \\ A^{EBT} & B^{EBT} & C^{EBT} & D^{EBT} & E^{EBT} & F^{EBT} \end{bmatrix} \begin{Bmatrix} YS^2 \\ YS \\ 1 \\ t_0^2 \\ t_0 \\ (YS)t_0 \end{Bmatrix}$$

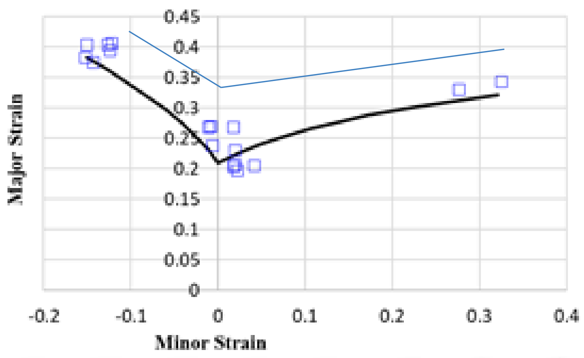
For one class: i.e. TRIP

PREDICT THE FLCS FOR 3RD GEN 980

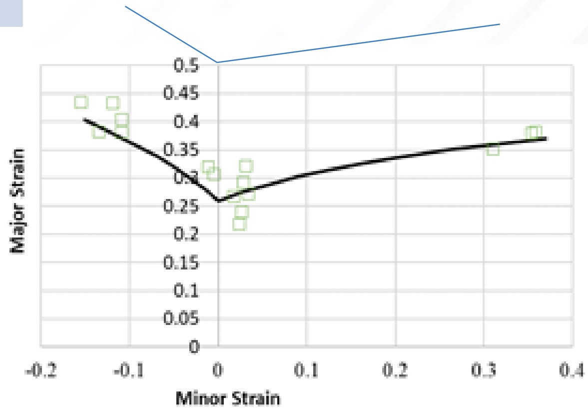
i	D_r^i	E_r^i	F_r^i
PS	0	0.023	0.352
UT	0	0.133	0.718
EBT	−0.332	1.387	1.480



0.8mm



1.4mm



2.3mm

Black solid lines are predicted by the present method

*Experimental data from [Huang and Shi 2018 SAE]

**Blue solid lines are predicted by Keeler's equation

PREDICTION OF FLCS FOR BORON STEEL AT HOT STAMPING TEMPERATURES

i	A_h^i	B_h^i	C_h^i	D_h^i	E_h^i	F_h^i
PS	0.002	−0.146	2.909	−0.296	1.467	−0.009
UT	0.002	−0.174	3.099	−0.630	1.288	0.023
EBT	0.002	−0.235	12.807	1.302	−7.196	0.066

Based on test data from [Zhou et al. 2017, Cui et al. 2015, Shi et al. 2016]

$$\begin{Bmatrix} \varepsilon_1^n(t_0, -0.5, Z') \\ g(t_0, \rho^{PS}, Z') \\ g(t_0, \rho^{EBT}, Z') \end{Bmatrix} = \begin{bmatrix} A^{UT} & B^{UT} & C^{UT} & D^{UT} & E^{UT} & F^{UT} \\ A^{PS} & B^{PS} & C^{PS} & D^{PS} & E^{PS} & F^{PS} \\ A^{EBT} & B^{EBT} & C^{EBT} & D^{EBT} & E^{EBT} & F^{EBT} \end{bmatrix} \begin{Bmatrix} (ln(Z'))^2 \\ lnZ' \\ 1 \\ t_0^2 \\ t_0 \\ (ln(Z'))t_0 \end{Bmatrix}$$

PREDICTION OF FLCS FOR BORON STEEL AT HOT STAMPING TEMPERATURES

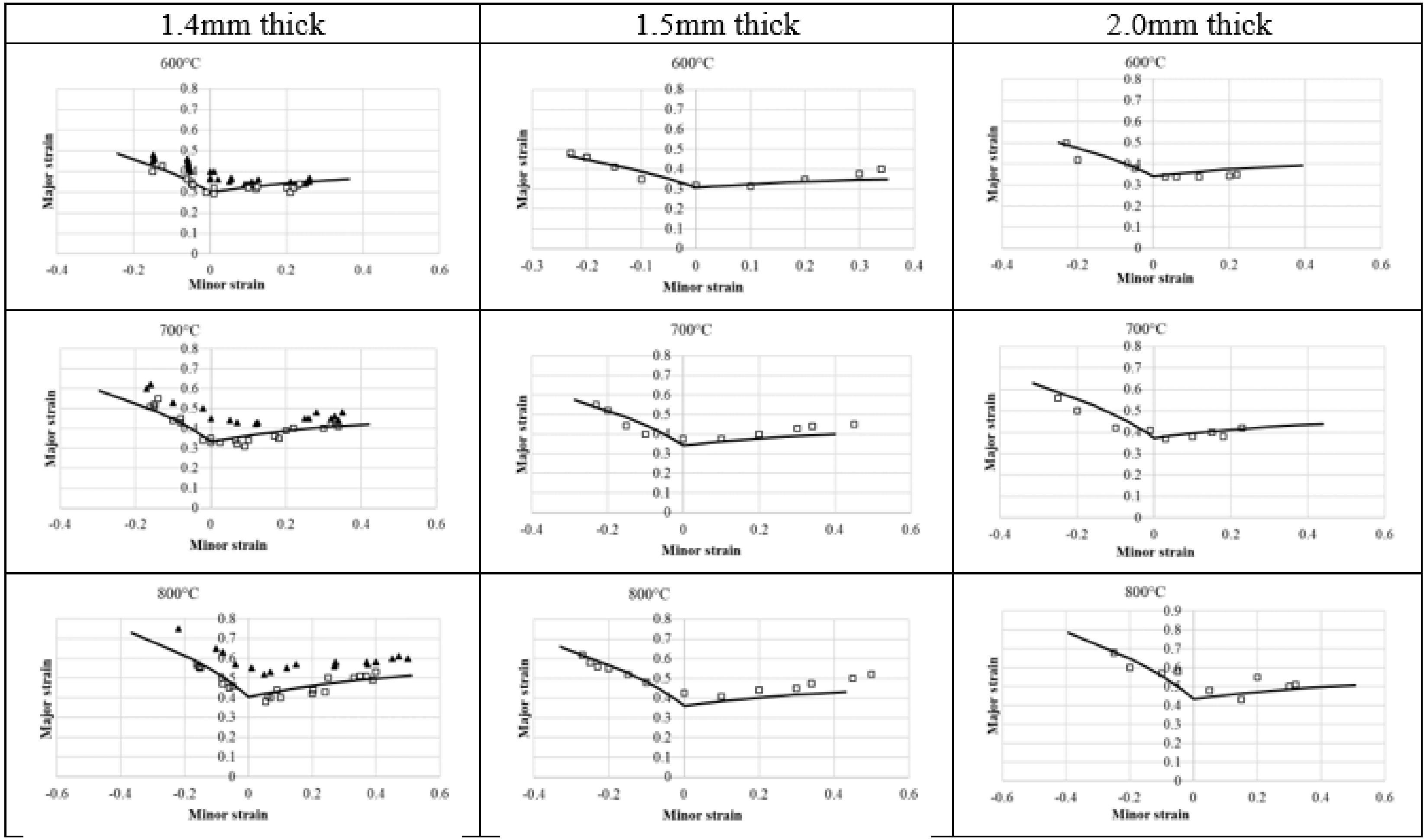
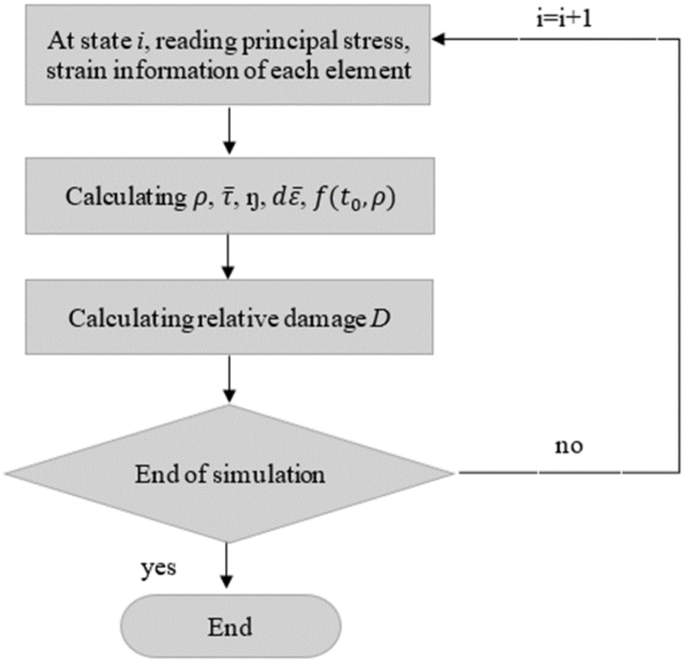


Figure 1 FLCs of a) 1.4mm thick; b) 1.5mm thick; c) 2.0mm thick boron steel predicted by present model (solid line) plotted against experimental measurement (rectangular marker) at hot stamping temperatures of 600˚C, 700˚C and 800˚C*

*: experimental data of 1.4mm thick, 1.5mm thick and .2.0mm thick is from [6, 16, 5]

PREDICTING FAILURE IN HOT STAMPING FEM SIMULATION

$$D = \frac{1}{\langle f(t_0, \rho)\rangle D_{cri}^{UT}(t_0, Z')} \int_0^{\bar{\varepsilon}^n(t_0,\rho,Z')} h(Z')\eta d\bar{\varepsilon}$$



MODELING ISOTHERMAL DOME TEST

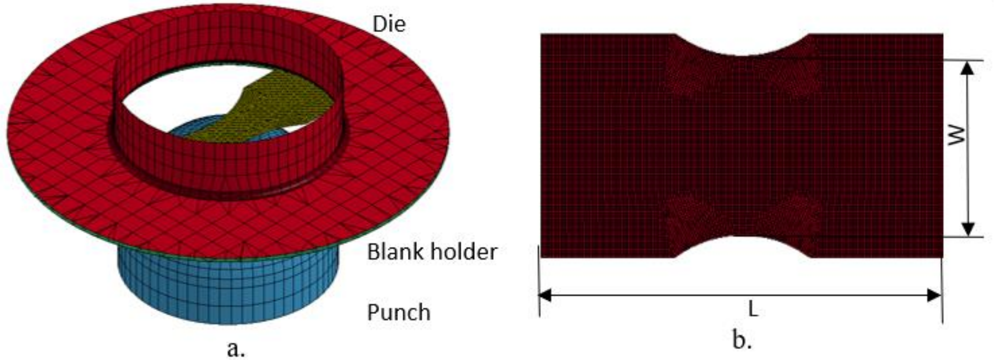
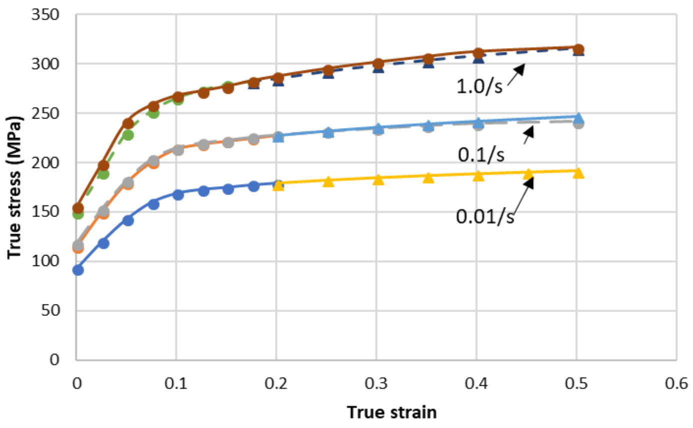
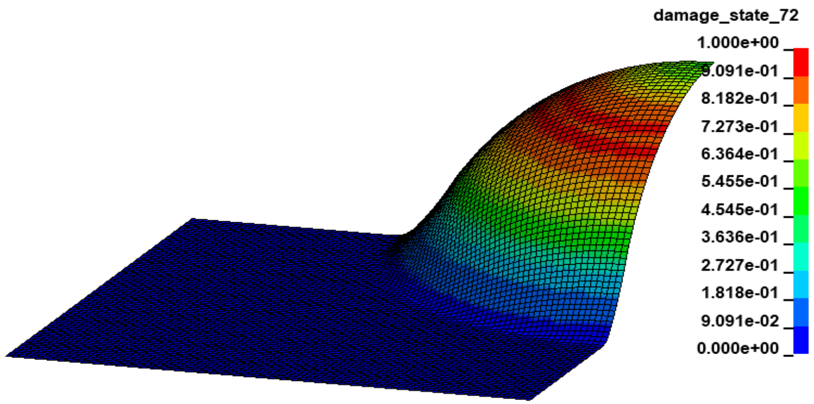


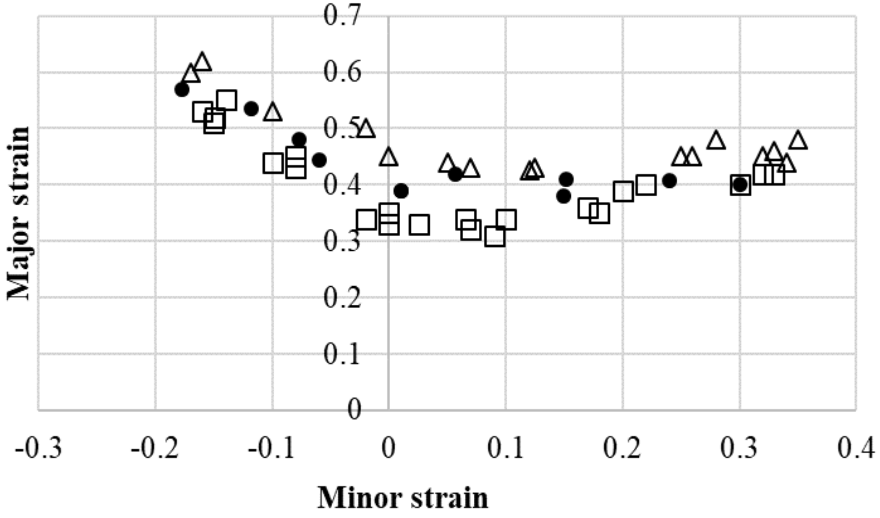
Figure 2 FEM model of the Nakajima dome test (a) tooling setup, (b) coupon with length (L) of 180mm and width (W) ranging from 20 to 180mm with an interval of 20mm

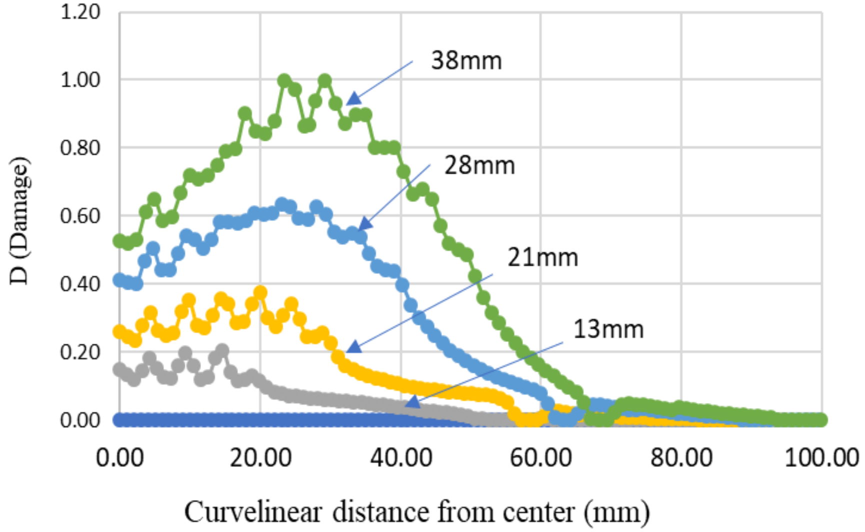


$$\bar{\sigma} = \bar{\sigma}_0 \left[1 + \left(\frac{\dot{\bar{\varepsilon}}^p}{C} \right)^{1/P} \right]$$

RESULTS



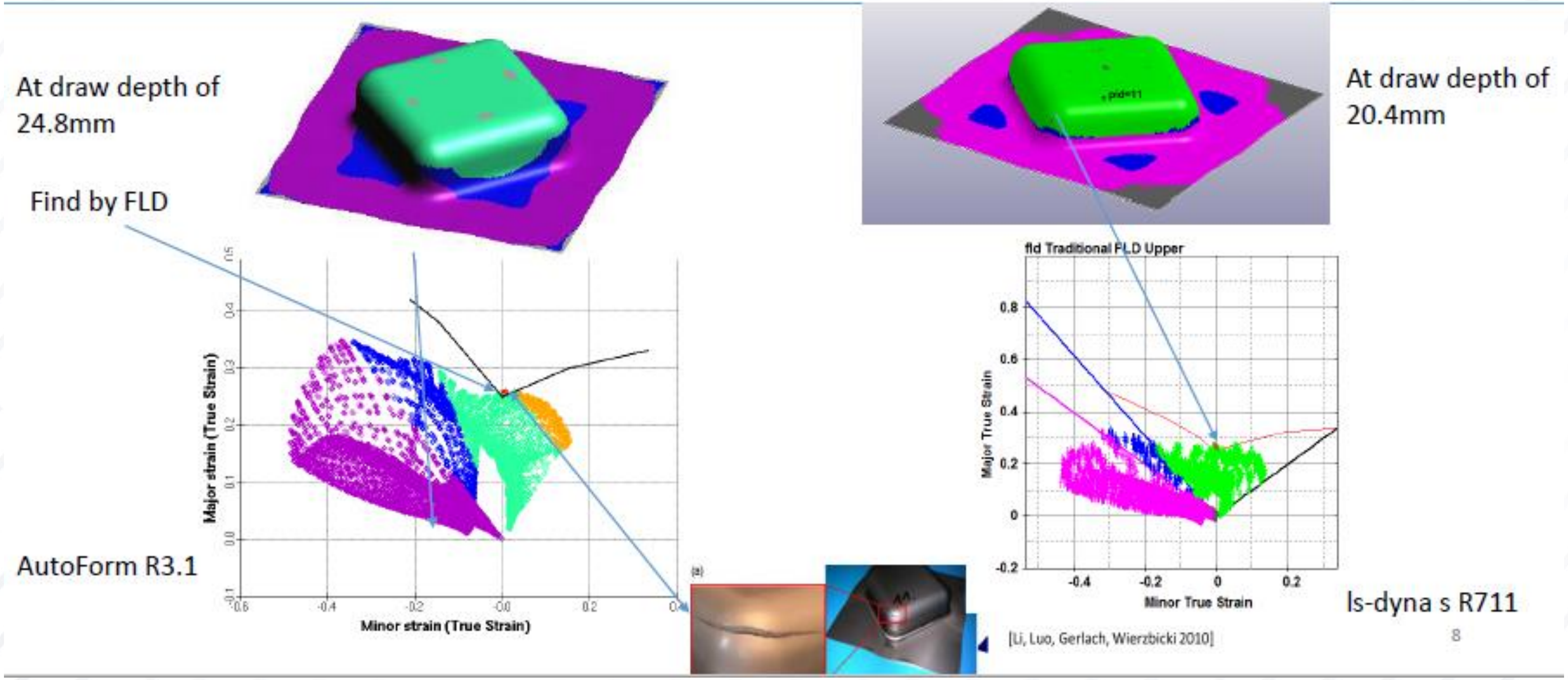




Limit strains predicted (black dots) vs. experimental measurements (triangular - critical, rectangular - LN)*

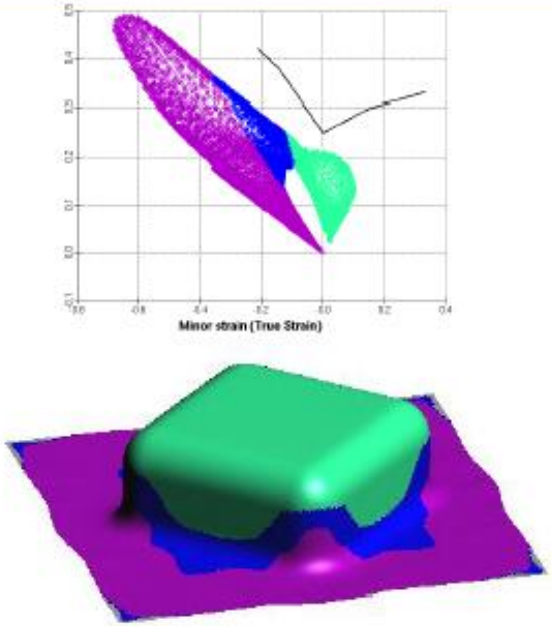
*: test data is from (Zhou et al. 2017)

ONE RELATED ISSUE – USING FLD

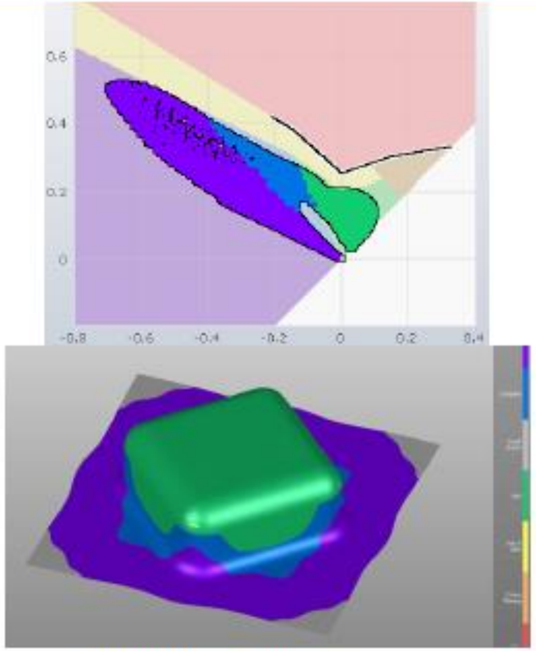


USING FLD

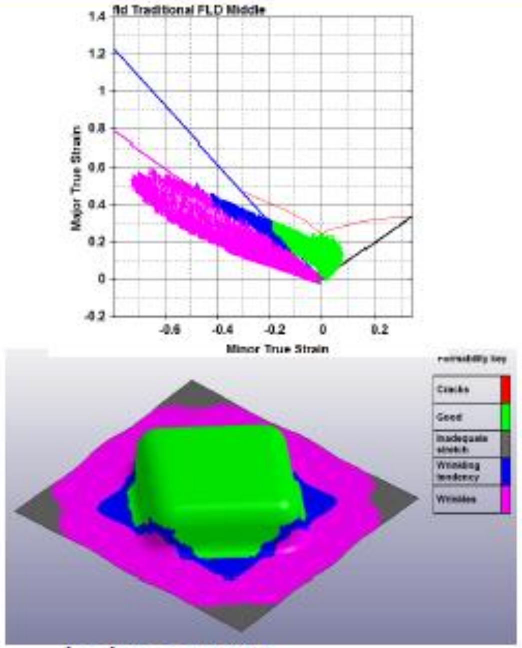
FLD at mid layer



Autoform R3.1



Autoform^plus R6



ls-dyna s R711

CONCLUSIONS AND DISCUSSION

Consistency, simplicity, cost saving

This may make it a practical way to model FLC for 3rd GEN.

$$\begin{Bmatrix} \varepsilon_1^n(t_0,-0.5,YS) \\ g(t_0,\rho^{PS},YS) \\ g(t_0,\rho^{EBT},YS) \end{Bmatrix} = \begin{bmatrix} A^{UT} & B^{UT} & C^{UT} & D^{UT} & E^{UT} & F^{UT} \\ A^{PS} & B^{PS} & C^{PS} & D^{PS} & E^{PS} & F^{PS} \\ A^{EBT} & B^{EBT} & C^{EBT} & D^{EBT} & E^{EBT} & F^{EBT} \end{bmatrix} \begin{Bmatrix} YS^2 \\ YS \\ 1 \\ t_0^2 \\ t_0 \\ (YS)t_0 \end{Bmatrix}$$

ACKNOWLEDGEMENTS

- General Motors Company for the permission to publish.
- Great support from the developers at LSTC.

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