Glass modeling in LS-DYNA

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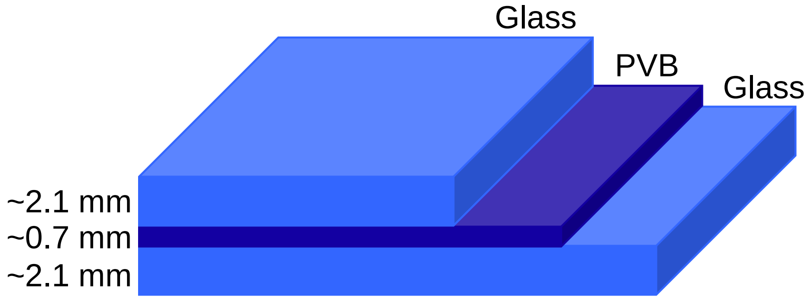
Content

- Common approach to model laminated safety glass
- material model *MAT_GLASS (*MAT_280)
  - Theory
  - Keyword *MAT_280
- PVB-layer
- application

Laminated safety glass

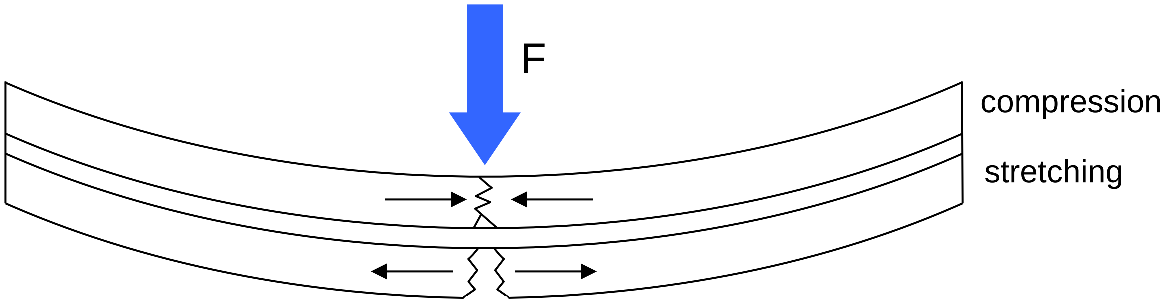
- Two types of safety glass commonly used:
  - Tempered glass ➔ side windows
  - Laminated glass ➔ windshields, panorama sunroofs



- Laminated glass consists of 3 layers
  - 2x glass
  - PVB interlayer

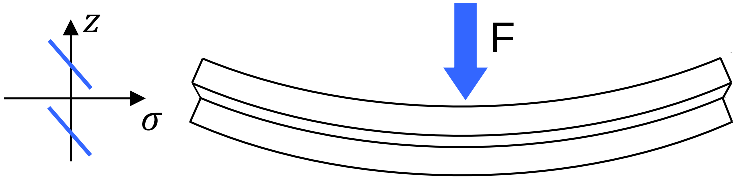
- Glass fragments are bonded

  ➔ Difficult mechanical behavior



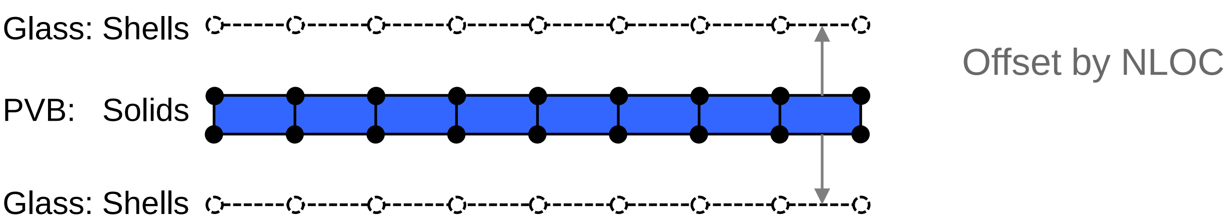
Modelling of laminated safety glass

- Discretization:
  - PVB: transverse shear deformation important
    ➔ **solid elements**
  - Glass: **shell elements**



- Contact between layers: **Shared nodes**

- Offset the glass layers by **NLOC** parameter

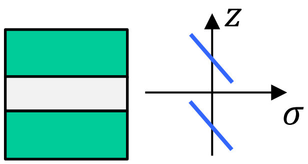



```
*SECTION_SHELL
$     SECID    ELFORM      SHRF       NIP     PROPT   QR/IRID     ICOMP     SETYP
        103         2       1.0         7       3.0       0.0
$        T1        T2        T3        T4      NLOC     MAREA
        2.1       2.1       2.1       2.1     -1.00
$
```

Modelling of laminated safety glass

- **Discretization PVB**:
  - solid elements
  - 1 solid element over thickness
  - elform 1 (under-integrated),
    elform -1 or -2 (for poor aspect ratio) or elform 2 (fully integrated)
  - hourglass stabilization HGID=6 and qh=0.5-0.8

- **Discretization glass layers**
  - shell elements
  - e.g. elform = 2 (under-integrated) … for *MAT_GLASS
  - hourglass stabilization HGID=4
  - sufficient number of integration points over thickness



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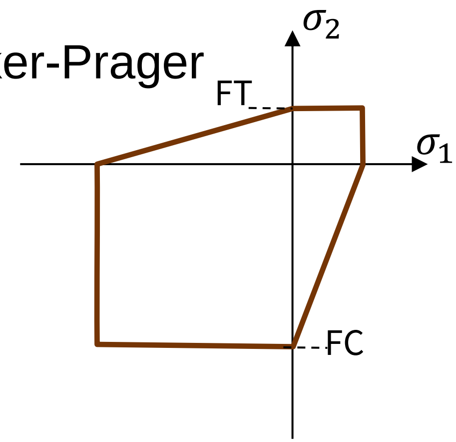
Material model *MAT_GLASS (*MAT_280)

- Smeared fixed crack material model
- Stress based **failure criteria with tension – compression asymmetry**
- **Treatment of failure without deleting elements**
- **Crack closure and opening effects**

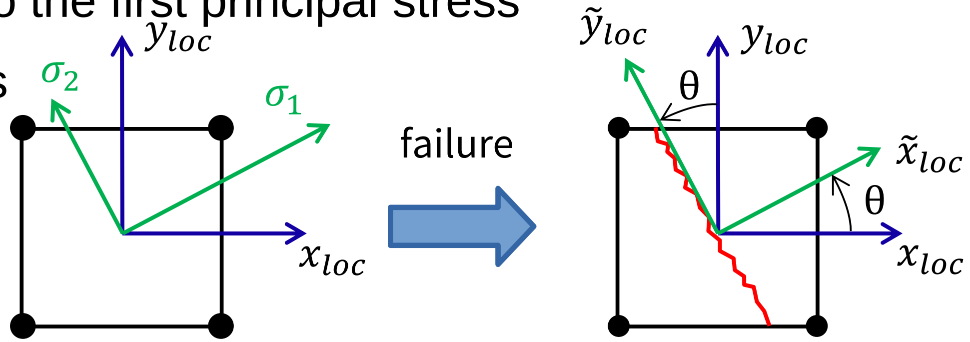
- Further: Easy to use, low computation times, usable in crash simulations
- For shell and thick shells elements (tshell, elform 1,2,6) and explicit analysis

Detection of failure – failure criteria

- Failure criteria: stress based: Rankine, Mohr-Coulomb, Drucker-Prager
- Failure:
  - Compressive failure: Material is 'crumbled'
  - Tensile failure: Single crack occurs



- Tensile Failure:
  - Crack direction perpendicular to the first principal stress
  - Local crack coordinate systems



  - Second crack can occur, orthogonal to the first crack
  - Cracks can open and close independently

*MAT_GLASS

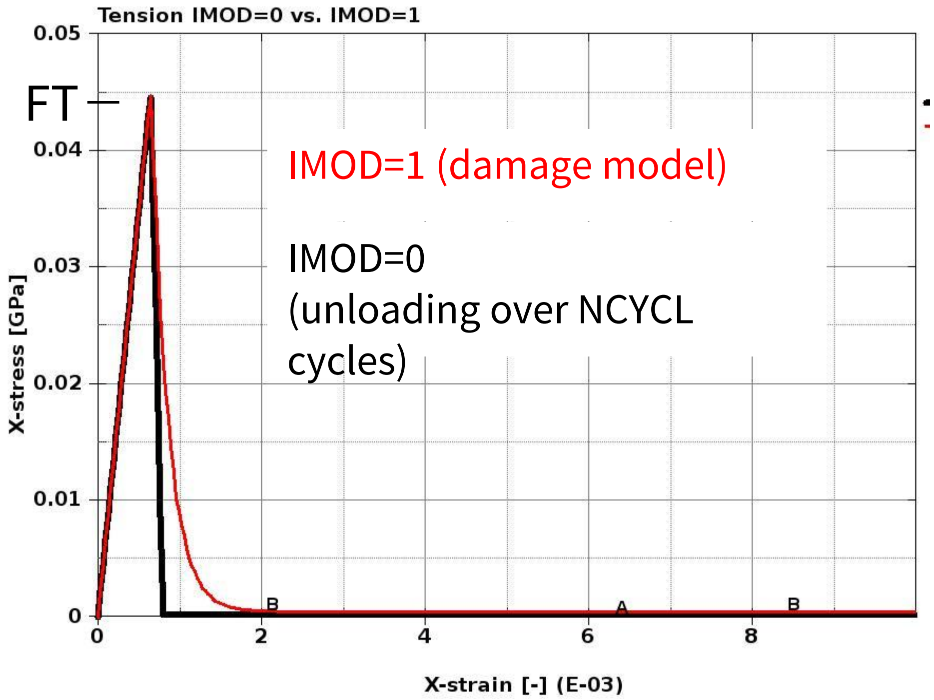
Softening

After a tensile crack is detected:

- Orthotropic material behavior in crack coordinate system
- Stress components which can no longer be carried are lowered in **NCYCR cycles or** with **damage model**

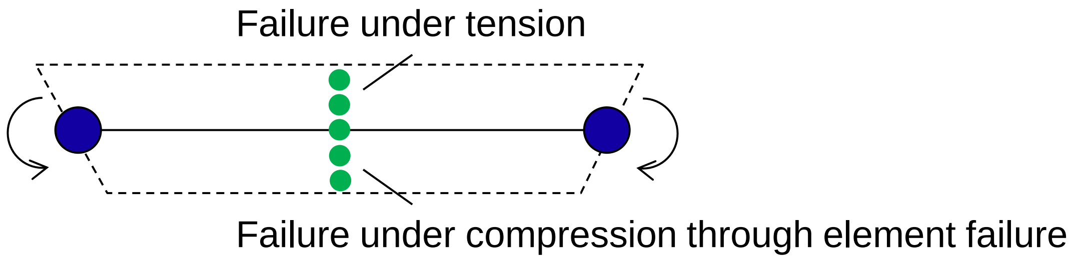
After compressive failure:

- All stress components are lowered in **NCYCR cycles or** with **damage model**



Element failure

- If a certain number of IP in one element failed, whole element will fail
- The crack direction in the IP which failed first sets the direction for the whole element
- Crack strain is computed individually in each IP



*MAT_GLASS

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	E	PR			IMOD	ILAW
Type	A8	F	F	F			F	F

Card 2	1	2	3	4	5	6	7	8
Variable	FMOD	FT	FC	AT	BT	AC	BC	FTSCL
Type	F	F	F	F	F	F	F	F

Card 3	1	2	3	4	5	6	7	8
Variable	SFSTI	SFSTR	CRIN	ECRCL	NCYCR	NIPF		
Type	F	F	F	F	F	F		

Optional card.

Card 4	1	2	3	4	5	6	7	8
Variable	EPSCR	ENGCRT	RADCRT	RATENL	RFILTF			
Type	F	F	F					

parameter from R9.0

parameter from R10.0

parameter from R9.2

parameter from R11.0

*MAT_GLASS (*MAT_280)

*MAT_GLASS (Parameters from R9.0)

- FMOD: Failure model (0.: Rankine (default), 1.: Mohr-Coulomb, 2.: Drucker-Prager)
- FT: Tensile strength
- FC: Compressive strength

- SFSTI: Stiffness scale factor in case of failure
  SFSTI = 0.1 means: stiffness is reduced to 10% of elastic stiffness at failure
- SFSTR: Stress scale factor in case of failure
- NCYCR: Number of cycles in which the stress is lowered to SFSTR * failure stress

- CRIN: Flag for crack strain initialization:
  0.: initial crack strain is strain when crack occurs (default)
  1.: initial crack strain is 0.0
- ECRCL: Crack strain from which on the crack is considered as completely closed

- NIPF: Number of failed integration points to fail all through thickness integration points

*MAT_GLASS (Parameters from R10.0)

stress reduction with damage model

- IMOD: Flag to choose unloading procedure, when critical stress is reached:
  EQ.0.0: Softening in NCYCR load steps (default),
  EQ.1.0: Damage model for softening

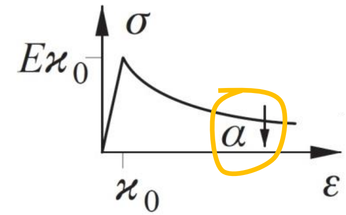
- ILAW: EQ.0.0: same damage evolution for tensile and compressive failure (default):

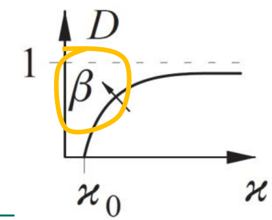
$$\mathrm{D} = 1 - \frac{\kappa^0}{\kappa}\left(1 - \alpha_{t,c} + \alpha_{t,c} e^{-\beta_{t,c}\,(\kappa - \kappa^0)}\right)$$

  EQ.1.0: damage evolution for tensile failure: $\mathrm{D} = 1 - \frac{\kappa^0}{\kappa}\left(1 - \alpha_t + \alpha_t e^{-\beta_t\,(\kappa - \kappa^0)}\right)$

  damage evolution compressive failure: $\mathrm{D} = 1 - \frac{\kappa^0}{\kappa}(1 - \alpha_c) - \alpha_c e^{-\beta_c\,(\kappa - \kappa^0)}$

- AT: tensile damage evolution parameter α_t. $0 \leq AT \leq 1.0$
- BT: tensile damage evolution parameter β_t. $BT \geq 0.0$
- AC: compressive damage evolution parameter α_c. $0 \leq AC \leq 1.0$
- BC: compressive damage evolution parameter β_c. $BC \geq 0.0$





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Increasing of tensile strength for first tensile crack (from R9.2):

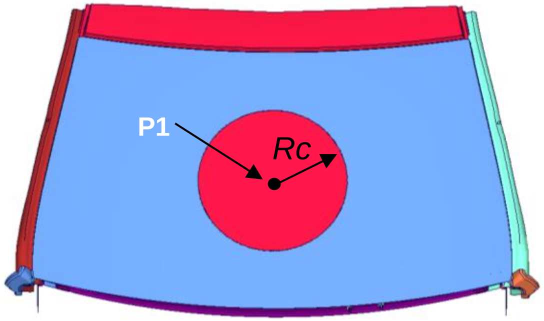
- FTSCL: If RATENL=0.:
  Factor, that scales tensile strength FT until the first tensile crack is detected.
  Thereafter, the tensile strength is set to FT.

Element deletion (from R11.0)

- EPSCR: >0: maximum effective strain strain $\varepsilon_{eff} = \sqrt{\frac{2}{3}\varepsilon_{ij}\varepsilon_{ij}}$ for element deletion
  <0: |EPSCR| is critical crack opening displacement (R11.1 needed)

Nonlocal failure criterion (from R11.0)

- ENGCRT: Critical energy for nonlocal failure criterion
- RADCRT: Critical radius for nonlocal failure criterion



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Nonlocal strain rate dependent tensile strength (from R11.0.0):

- RATENL: quasi-static strain rate threshold value.
  If RATENL≠0, the nonlocal strain rate dependent tensile strength adaption is activated.

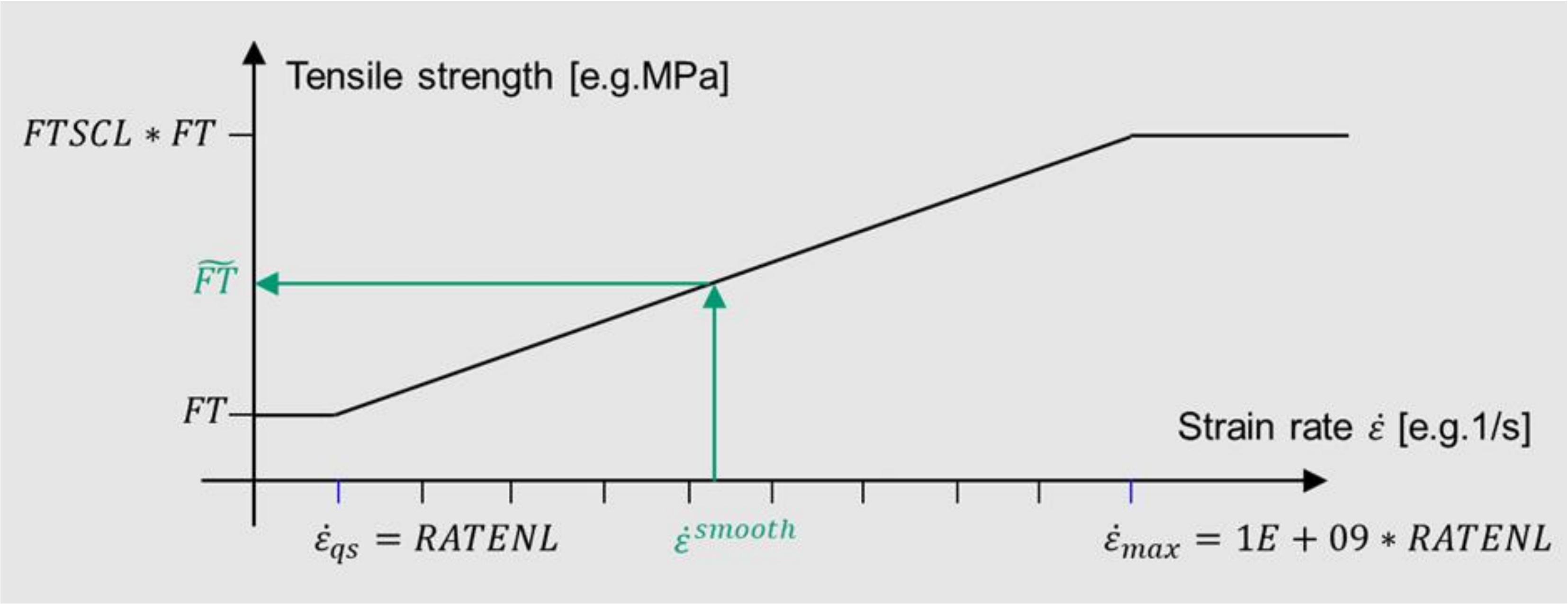
- FTSCL: If RATENL≠0.:
  Factor, that scales tensile strength FT until the information of a neighbor element is transmitted, that the neighbor-element is cracked

- RFILTF: If RATENL ≠0.:
  smoothing of effective strain rate for evaluation of current tensile strength:
  $\dot{\varepsilon}^{smooth} = RFILTF * \dot{\varepsilon}^{smooth,n} + (1. - RFILTF) * \dot{\varepsilon}^{n+1}$
  RFILTF=0.: no smoothing
  RFILTF=0.99: strong smoothing

*MAT_GLASS

Nonlocal strain rate dependent tensile strength (from R11.0.0):

- Initialization of all Integration points with tensile strength: $FT_{initial} = FT_{max} = FTSCL * FT$



At the moment: $\dot{\varepsilon}_{max}$ is not a material parameter

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Nonlocal strain rate dependent tensile strength (from R11.0.0):

- If one integration point in an element recognizes failure, the tensile strength in the neighbor-elements is adapted to

$$\widetilde{FT} = \begin{cases} FT_{min} = FT & if \quad \dot{\varepsilon} \leq RATENL \\ FT + (FTSCL * FT - FT) * \dfrac{\log\left(\dot{\varepsilon}/\dot{\varepsilon}_{qs}\right)}{\log\left(\dot{\varepsilon}_{max}/\dot{\varepsilon}_{qs}\right)} & if \quad RATENL \leq \dot{\varepsilon} \leq \dot{\varepsilon}_{max} \\ FTSCL * FT & if \quad \dot{\varepsilon} \geq \dot{\varepsilon}_{max} \end{cases}$$

*MAT_GLASS

History variables – post-processing:

- history variable 1: Crack Flag
  - 1 = one tensile crack in element (failure under tension)
  - 2 = two tensile cracks in element (failure under tension)
  - -1 = failure under compression

- History variable 2:

  1st crack: direction of maximum principle stress (angle in rad) related to element direction

  (direction of first tensile crack is perpendicular to this direction)

- History variable 3:

  2nd crack: direction of 2nd principle stress (angle in rad) related to element direction

  (direction of second tensile crack is perpendicular to this direction)

*MAT_GLASS

History variables – post-processing:

- history variable 4:

  failure criterion value

- History variable 7: (from R11.0.0)

  currently used tensile strength if RATENL≠0.

- History variable 8: (from R11.0.0)

  current strain rate

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Remarks to PVB behavior

- strongly rate dependent nonlinear elastic
- Hysteresis
- Temperature dependent

- ***MAT_SIMPLIFIED_RUBBER (*MAT_181)**
  take care about really smooth curves and smooth derivative in LC/TBID
  for nonlinear-elastic rate dependent stress-strain behavior

- ***MAT_HYPERELASTIC_RUBBER (*MAT_077)**

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