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Powering Innovation That Drives Human Advancement

A new Basic Incremental Failure model in LS-DYNA

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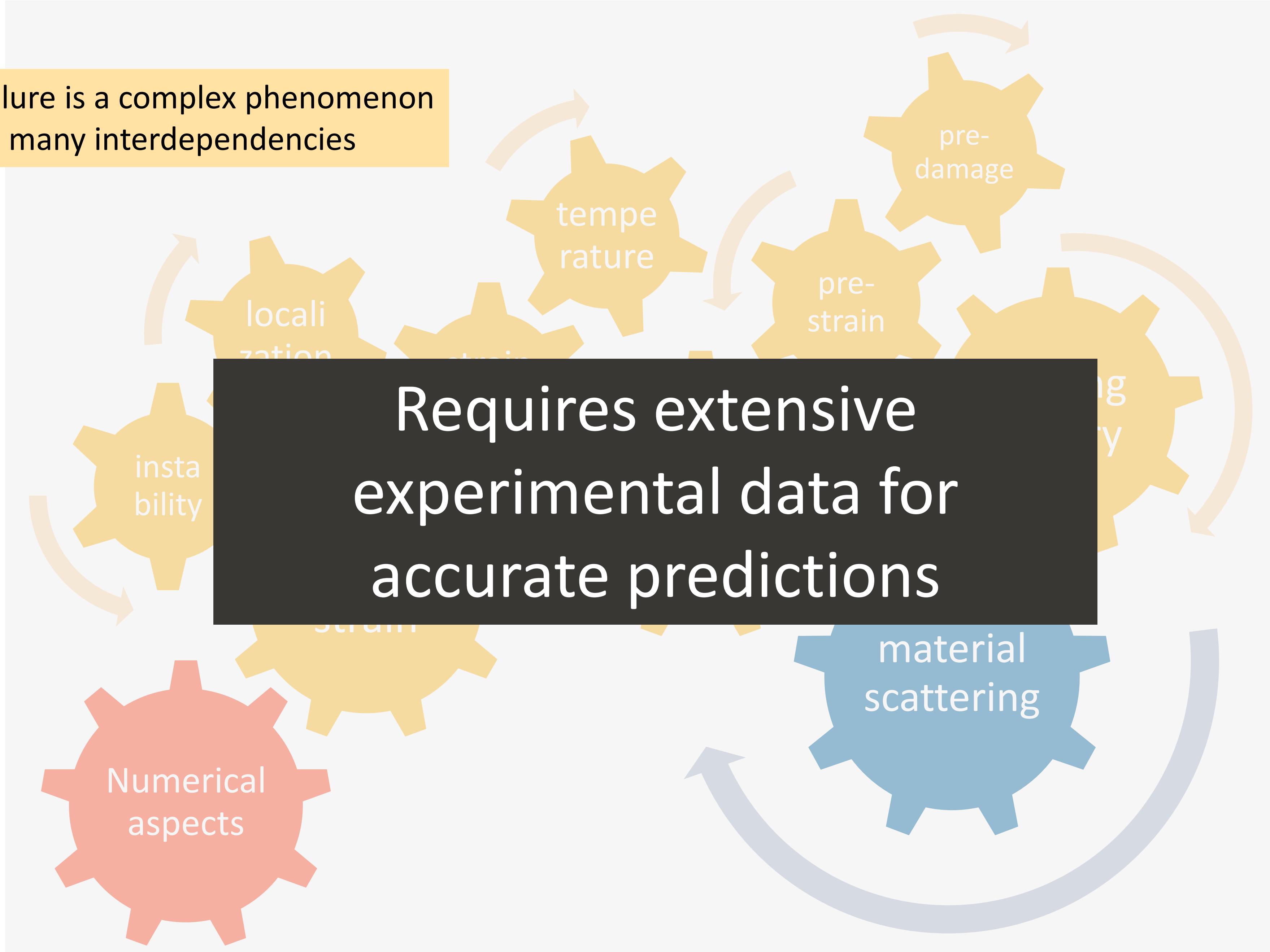
BIF

Why BIF?

Ductile failure is a complex phenomenon with many interdependencies



Requires extensive experimental data for accurate predictions

Why BIF?

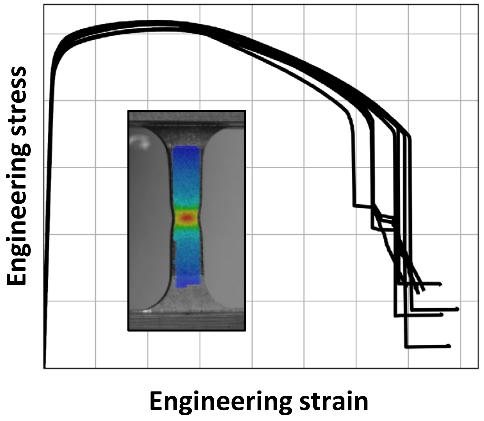
In many cases, extensive experimental data is challenging:

- New alloys
- Budget restrictions
- Time constraints
- Low relevance of target component
- Difficulty in sample extraction
- Lack of experience with sophisticated models

Can we potentialize the quality of failure predictions using the same amount of experimental data?

Typical solution: Usage of FAIL or MXEPS

- Disadvantages:
  - No deformation history
  - No stress state dependence
  - No regularization
  - …
- Advantages:
  - One single parameter in the input
  - No need for extensive experimental data **(typically, only a tensile test available)**



What is BIF? Keyword structure (LS-DYNA R16)

Number/percentage of failed integration points for element erosion

Failed volume fraction for element erosion (for high order solids and IGA)

Set NEROD=1 to suppress element erosion

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$      MID                      NUMFIP   VOLFRAC     NEROD
         1                         -80
$     EPSF        LCSS         LCREGD      LCSRS    DMGEXP
       0.7                        100                    2
```

True equivalent plastic strain at failure for triax=1/3 and lode=1.0

Base hardening curve for failure curve/surface

0/blank: default value → first curve in table is considered

Curve for element size regularization

Curve for strain rate dependence of failure

Exponent for damage accumulation

Recommendation:
1 → brittle metals, plastics (default)
2 → ductile metals

What is BIF? Failure curve (shells) or surface (solids)

True equivalent plastic strain at failure for triax=1/3 and lode=1.0

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID                NUMFIP   VOLFRAC     NEROD
          1
$      EPSF      LCSS      LCREGD     LCSRS    DMGEXP
        0.7                   100                   2
```

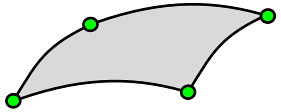
Cockcroft-Latham criterion

$$\int_0^{\varepsilon_f} \max(\sigma_1, 0)\, d\varepsilon^p \leq W_c$$

shells

solids

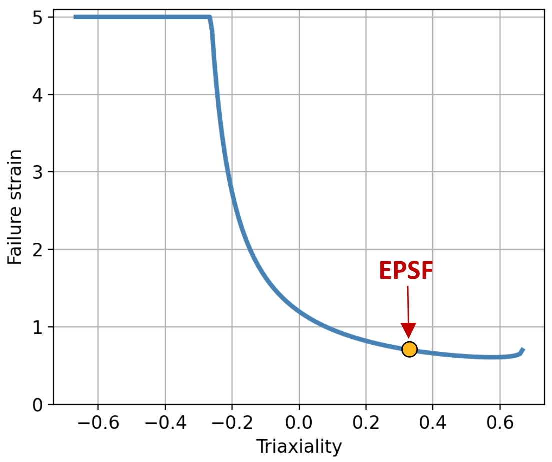
Automatic generation of the failure curve (shells) or failure surface (solids) done by LS-DYNA

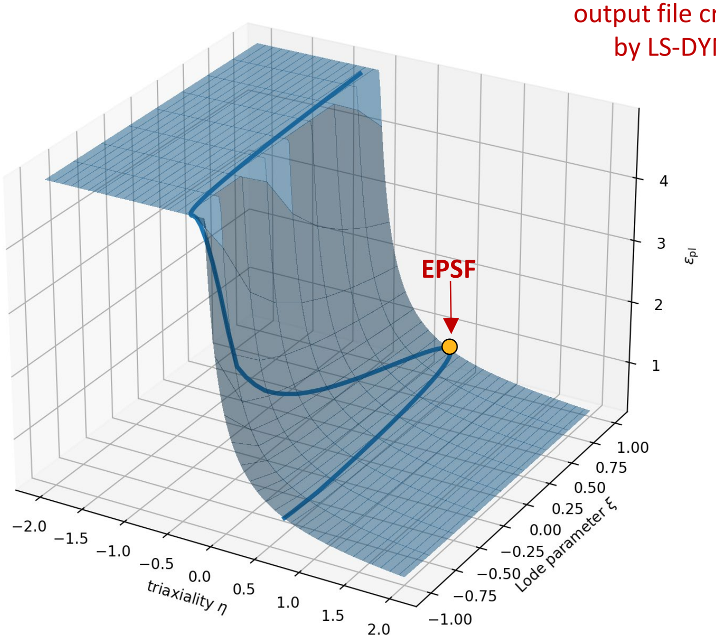


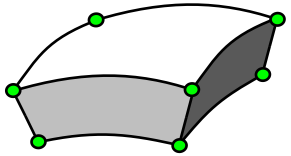
output file created by LS-DYNA

mabif_crvtbl

```
*KEYWORD
*DEFINE_CURVE
$ failure curve for MID 1 (PID=1)
   1001601
$          triaxiality        failure strain
        -6.666667E-01          4.999900E+00
        -6.600000E-01          4.999900E+00
        -6.533333E-01          4.999900E+00
        -6.466667E-01          4.999900E+00
        -6.400000E-01          4.999900E+00
        -6.333333E-01          4.999900E+00
        -6.266667E-01          4.999900E+00
        -6.200000E-01          4.999900E+00
        -6.133333E-01          4.999900E+00
        -6.066667E-01          4.999900E+00
        -6.000000E-01          4.999900E+00
        -5.933333E-01          4.999900E+00
        -5.866667E-01          4.999900E+00
        -5.800000E-01          4.999900E+00
        -5.733333E-01          4.999900E+00
        -5.666667E-01          4.999900E+00
        -5.600000E-01          4.999900E+00
        -5.533333E-01          4.999900E+00
        -5.466667E-01          4.999900E+00
        -5.400000E-01          4.999900E+00
        -5.333333E-01          4.999900E+00
        -5.266667E-01          4.999900E+00
        -5.200000E-01          4.999900E+00
        -5.133333E-01          4.999900E+00
```







output file created by LS-DYNA

mabif_crvtbl

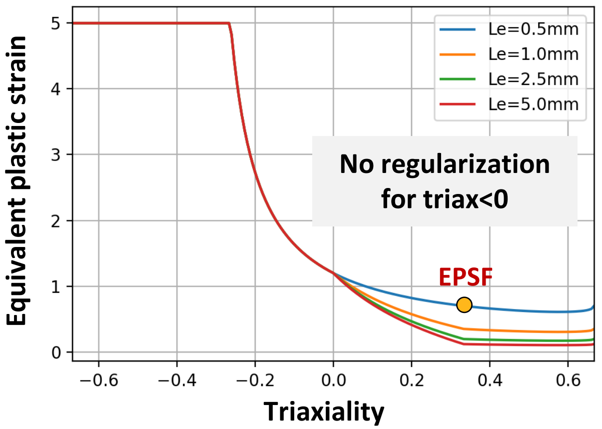
```
*KEYWORD
*DEFINE_TABLE
$ failure table for MID 1 (PID=1)
   1001602
$       Lode parameter
        -1.000000E+00
        -7.500000E-01
        -5.000000E-01
        -2.500000E-01
         0.000000E+00
         2.500000E-01
         5.000000E-01
         7.500000E-01
         1.000000E+00
*DEFINE_CURVE
   1001603
$          triaxiality        failure strain
        -2.000000E+00          4.999900E+00
        -1.980000E+00          4.999900E+00
        -1.960000E+00          4.999900E+00
        -1.940000E+00          4.999900E+00
        -1.920000E+00          4.999900E+00
        -1.900000E+00          4.999900E+00
        -1.880000E+00          4.999900E+00
        -1.860000E+00          4.999900E+00
        -1.840000E+00          4.999900E+00
        -1.820000E+00          4.999900E+00
        -1.800000E+00          4.999900E+00
        -1.780000E+00          4.999900E+00
        -1.760000E+00          4.999900E+00
        -1.740000E+00          4.999900E+00
```

What is BIF? LCREGD, LCSRS and DMGEXP (optional flags)

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID                 NUMFIP   VOLFRAC     NEROD
          1                    -80
$      EPSF      LCSS       LCREGD     LCSRS    DMGEXP
        0.7                    100       200         2
```

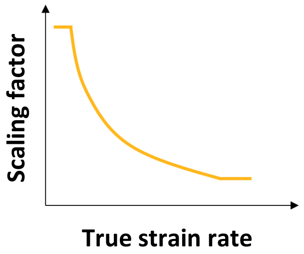
LCREGD (regularization)

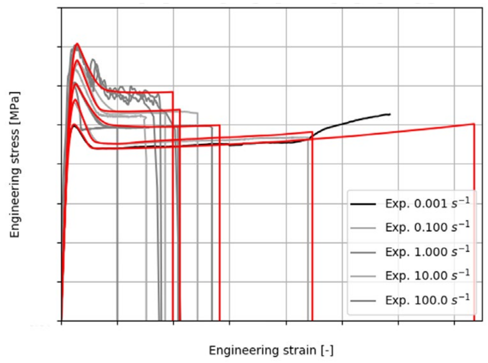
```
*DEFINE_CURVE
$      LCID        SIDR        SCLA        SCLO
        100
$        ELEMENT SIZE            REG. FACTOR
                  0.5                   1.00
                  1.0                   0.50
                  2.5                   0.28
                  5.0                   0.17
```



LCSRS (strain rate dependence)

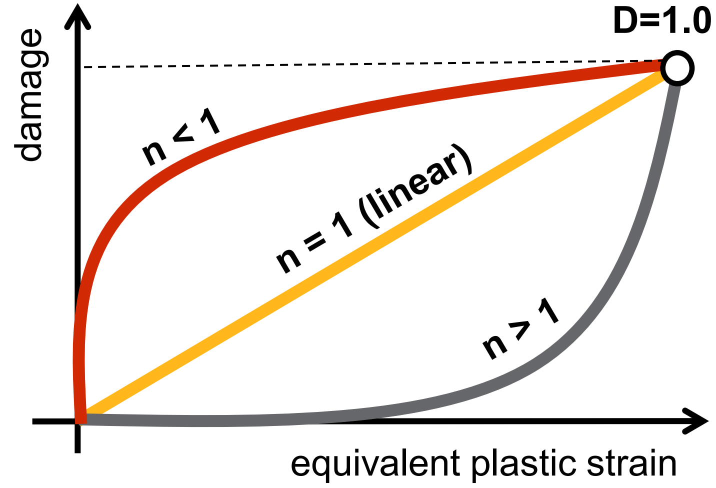
```
*DEFINE_CURVE
$      LCID        SIDR        SCLA        SCLO
        200
$   TRUE STRAIN RATE        SCALING FACTOR
             1.0E-07                   1.0
             1.0E-03                   0.9
             1.0E-01                   0.6
             1.0E+00                   0.6
```





DMGEXP

$$\Delta D = \frac{\mathrm{DMGEXP}}{\varepsilon_{fail}(\eta)} D^{\left(1-\frac{1}{\mathrm{DMGEXP}}\right)} \Delta\varepsilon_{eq}^{p}$$



What is BIF? History variables

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID                 NUMFIP   VOLFRAC     NEROD
          1                    -80
$      EPSF      LCSS       LCREGD     LCSRS    DMGEXP
        0.7                                          2
```

d3hsp:

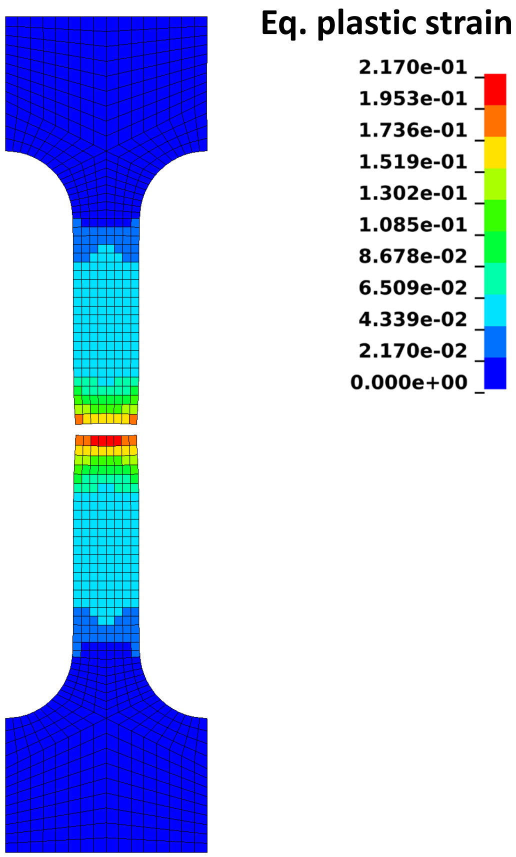
```
    basic incremental failure (BIF):
        failure strain                                  =   7.0000E-01
        hardening curve                                 =            0
        regularization curve                            =            0
        rate dependent scaling curve                    =            0
        damage exponent                                 =   2.0000E+00
        not erode flag (0:off, 1:on)                    =            0
        first damage history variable   - see BIF history listing below

 **********************************************************************

        GISSMO and BIF damage history listing

        PID 1 : first BIF history variable ND    = 6
```

History Variable #	Description
ND	Damage parameter D ($10^{-20} < D \leq 1$)
ND + 1	Equivalent plastic strain
ND + 2	Regularization factor for failure strain (determined from LCREGD)
ND + 3	Calculated element size, l_e
ND + 4	Number of IPs/layers (NUMFIP > 0/< 0) that must fail before an element gets deleted
ND + 5	Triaxiality variable, $\eta = \sigma_H/\sigma_M$
ND + 6	Lode parameter value L
ND + 7	Averaged triaxiality: $\eta_{n+1}^{\text{avg}} = \frac{1}{D_{n+1}}\left(D_n \times \eta_n^{\text{avg}} + (D_{n+1} - D_n) \times \eta_{n+1}\right)$
ND + 8	Averaged Lode parameter: $L_{n+1}^{\text{avg}} = \frac{1}{D_{n+1}}\left(D_n \times L_n^{\text{avg}} + (D_{n+1} - D_n) \times L_{n+1}\right)$
ND + 9	Alternative damage value: $D^{1/\text{DMGEXP}}$

How to use BIF?
Example #1: Tensile test with target element size (Le=2.5mm)

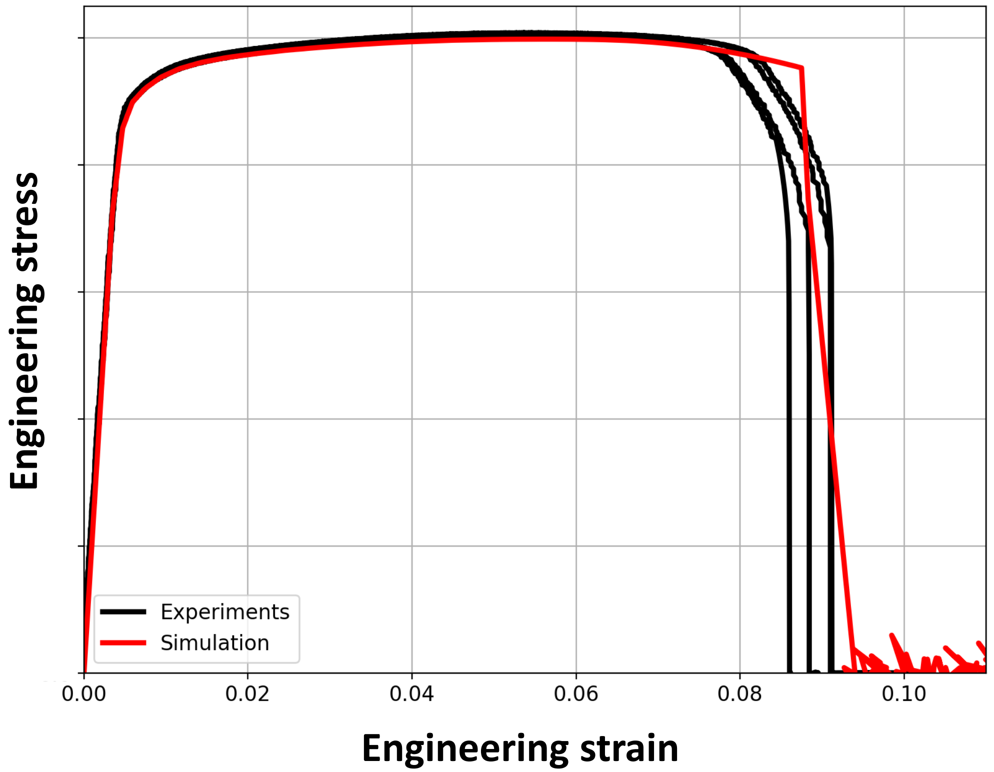
Complex phase steel

A80 tensile test



Solution time: 1 minute (8 procs)

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID                NUMFIP   VOLFRAC     NEROD
          1                   -80
$      EPSF        LCSS    LCREGD     LCSRS    DMGEXP
        0.2                                         2
```



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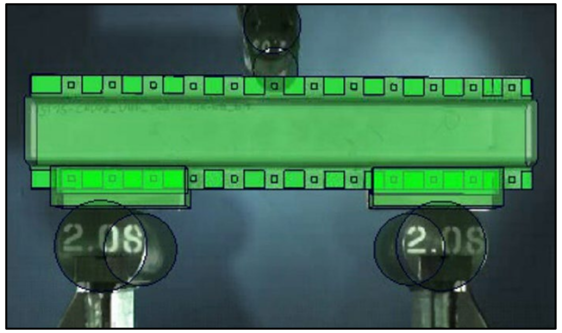
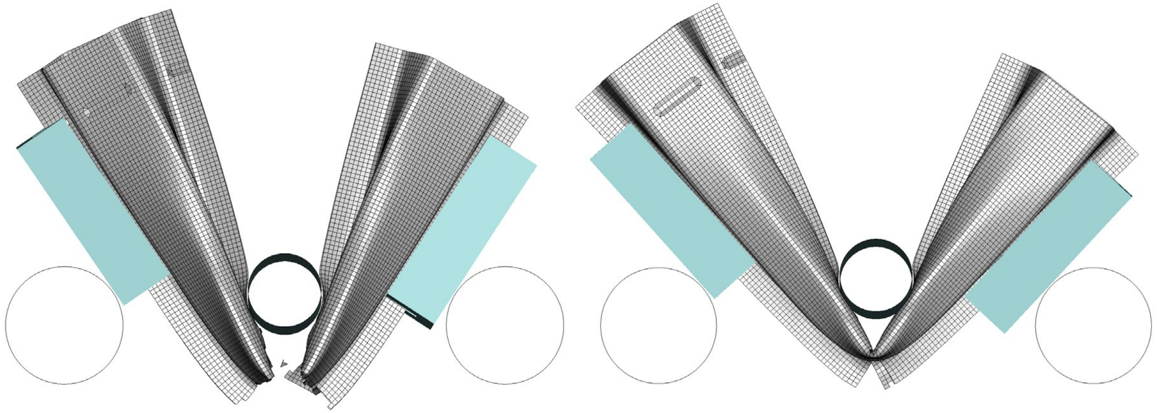
How to use BIF?
Example #1: Tensile test with target element size (Le=2.5mm)

Complex phase steel

Three-point bend





FAIL (MAT24)

BIF

Axial crushing

FAIL (MAT24)

1635 failed elements

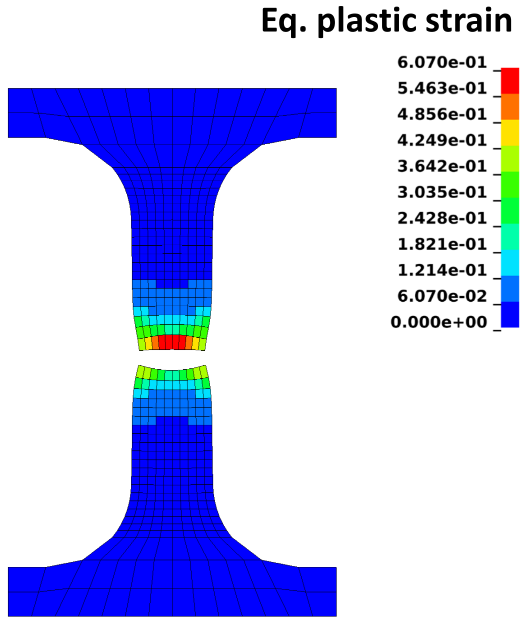
BIF

509 failed elements

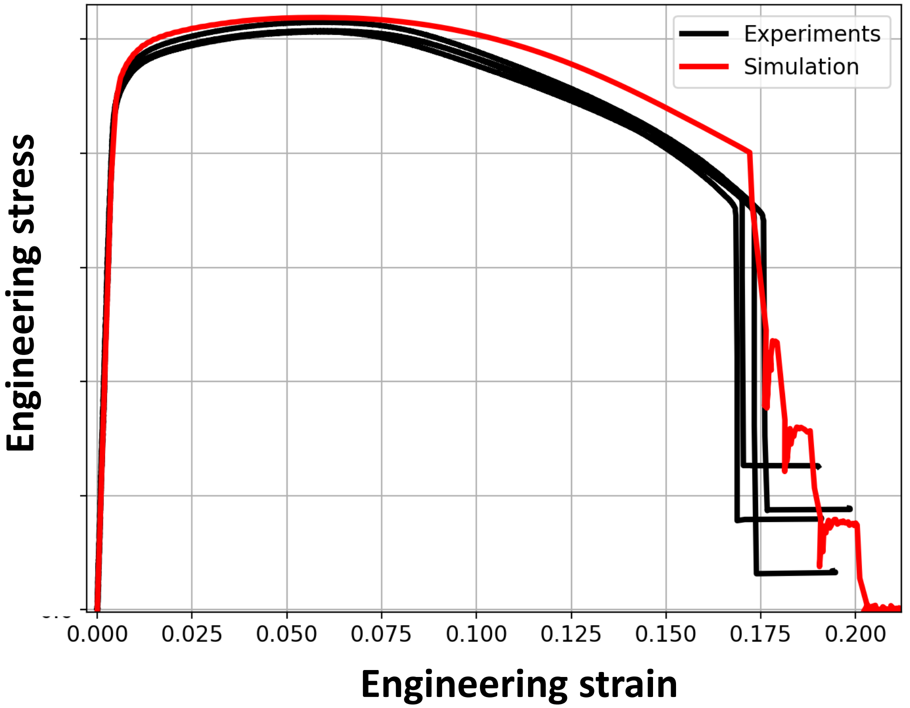
How to use BIF?
Example #2: Tensile test with Le=0.5mm + Regularization

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID              NUMFIP   VOLFRAC     NEROD
          1                 -80
$      EPSF      LCSS    LCREGD     LCSRS    DMGEXP
        0.7                 100                   2
```

Small tensile test (A10)



Solution time: 20 seconds (8 procs)



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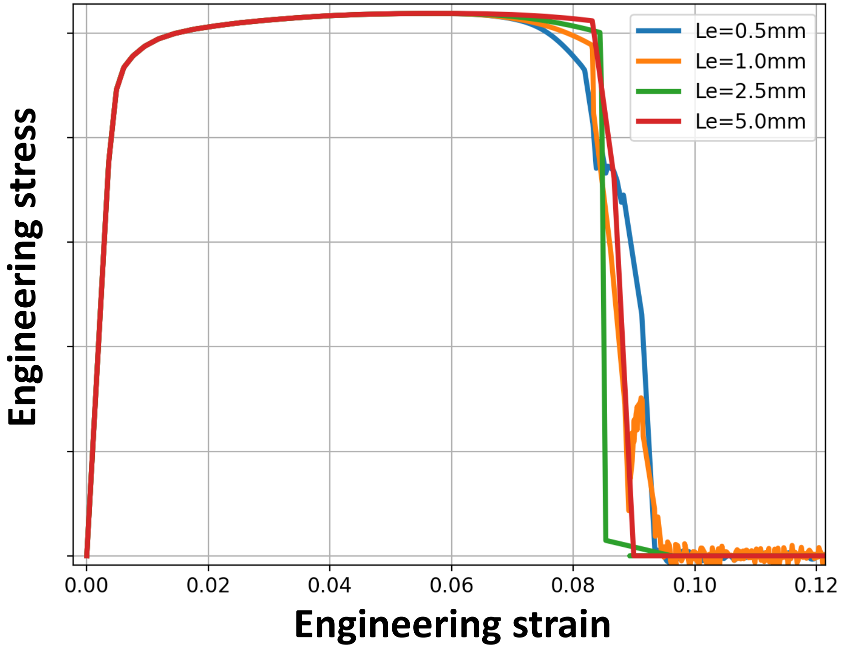
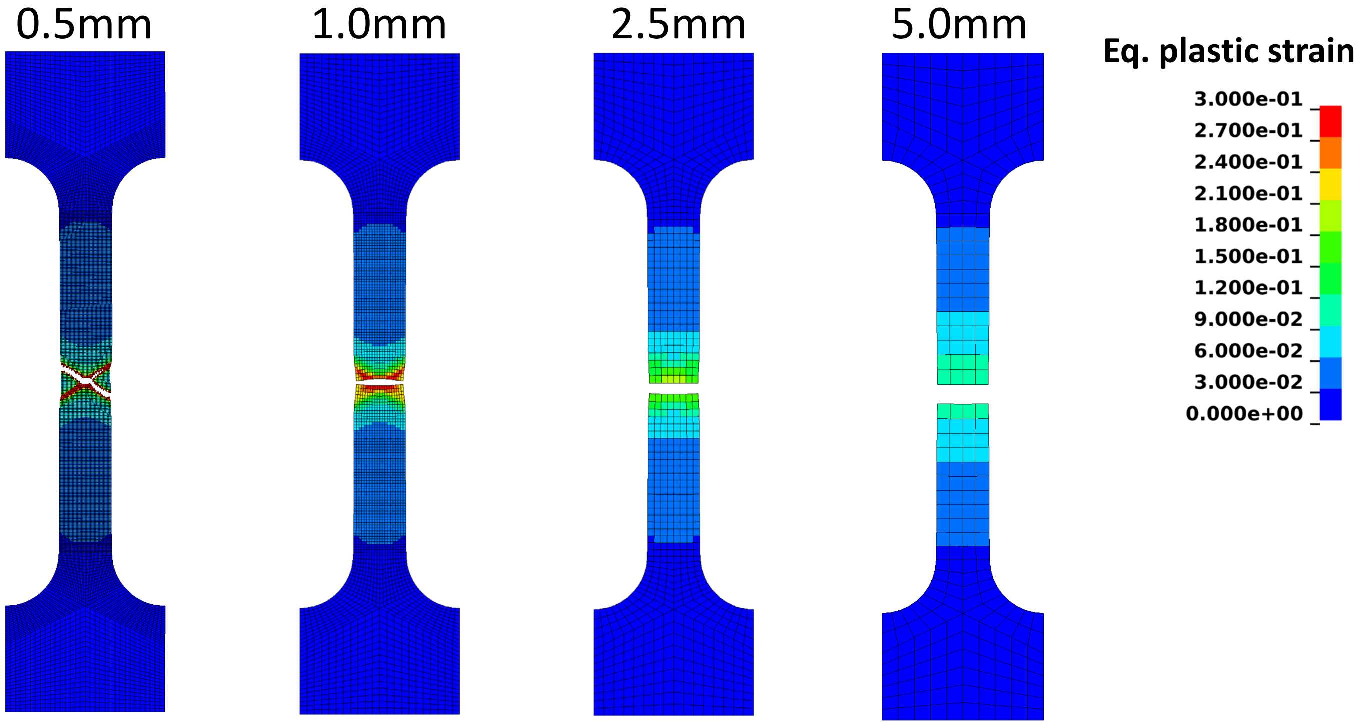
Complex phase steel

How to use BIF?
Example #2: Tensile test with Le=0.5mm + Regularization

```
*DEFINE_CURVE
$      LCID        SIDR        SCLA        SCLO
        100
$          ELEMENT SIZE            REG. FACTOR
                    0.5                   1.00
                    1.0                   0.50
                    2.5                   0.28
                    5.0                   0.17
```



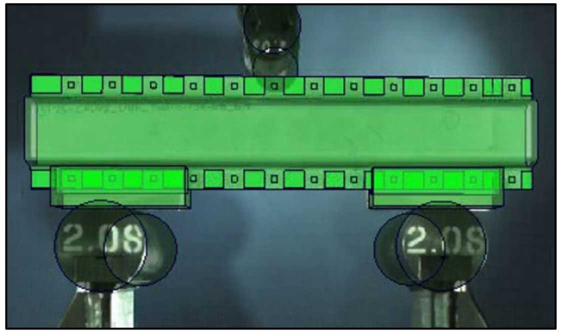

```
*MAT_ADD_BASIC_INCREMENTAL_FAILURE
$       MID                NUMFIP   VOLFRAC     NEROD
          1                   -80
$      EPSF      LCSS      LCREGD     LCSRS    DMGEXP
        0.7                   100                   2
```

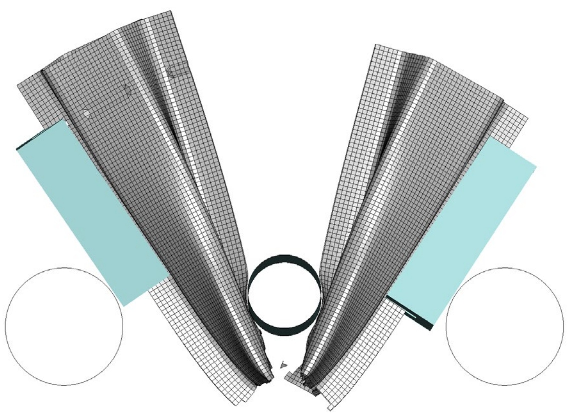


How to use BIF?
Example #2: Tensile test with Le=0.5mm + Regularization

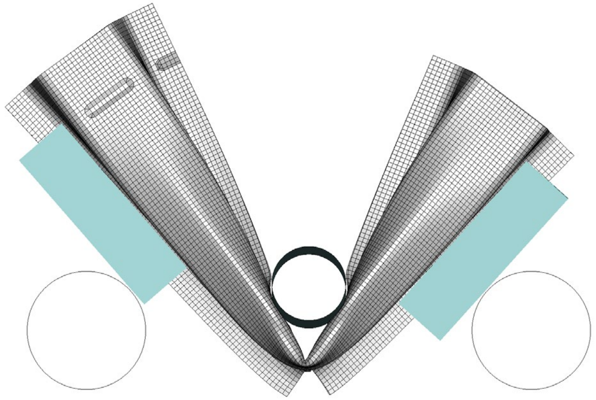
Complex phase steel

Three-point bend





FAIL (MAT24)



BIF

Axial crushing

Less failed elements, simulation closer to experimental result

FAIL (MAT24)

1635 failed elements

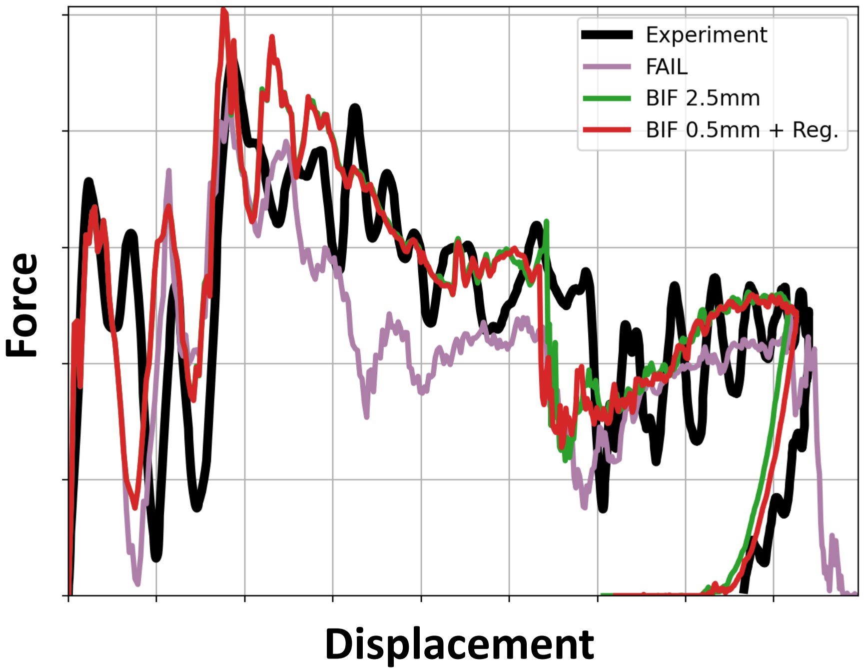
BIF

352 failed elements

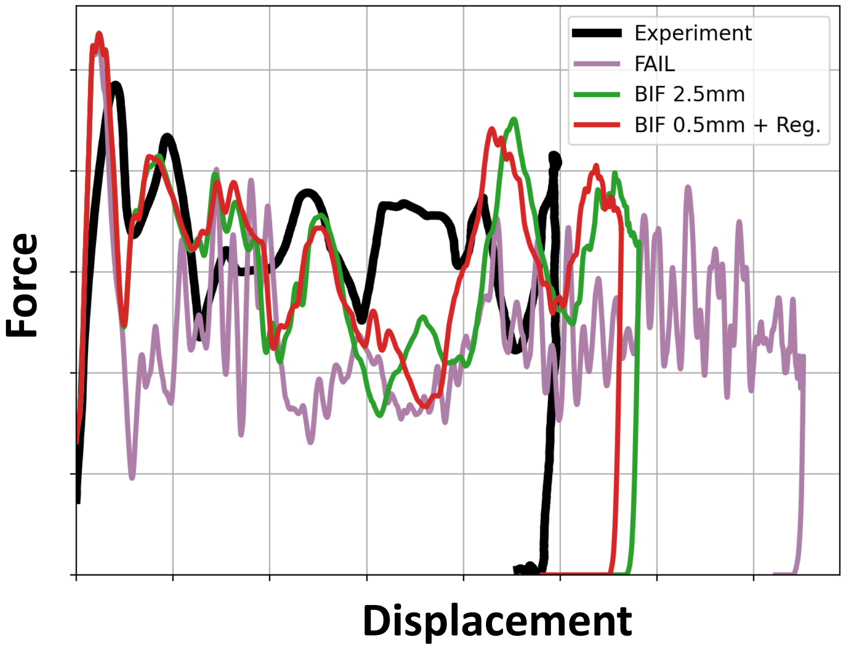
How to use BIF?
Comparison between #1 and #2 (Force vs. displacement)

Complex phase steel

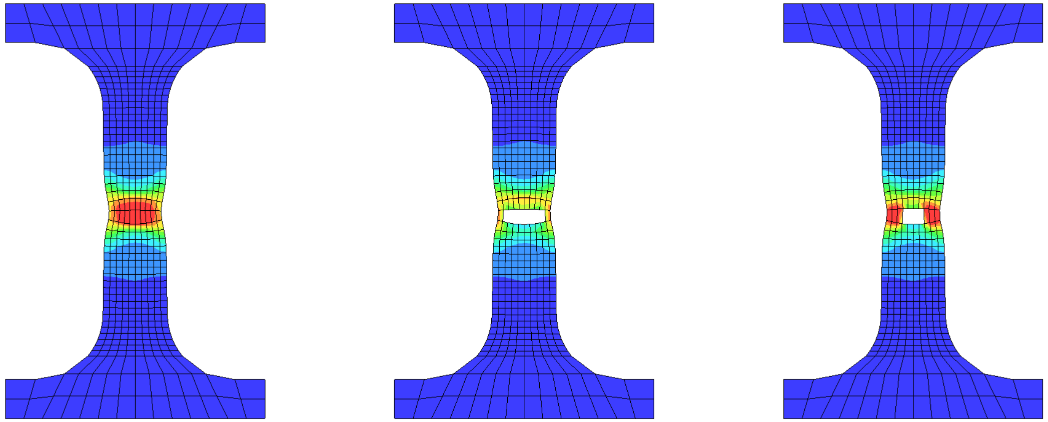
Three-point bend



Axial crushing



How fast? Performance study (on one single processor)



*MAT_024	*MAT_024 + BIF	*MAT_024 + GISSMO

ls-dyna_mpp_d_DEV-107858-g3d1e917091 double precision, L_e=0.5mm, ELFORM=16

	Element processing	CPU time per zone cycle	Total time	Factor
***MAT_024**	92%	1044 nanosec	0min35sec	1.0
***MAT_024 + BIF**	94%	1637 nanosec	0min53sec	1.51
***MAT_024 + GISSMO**	95%	2079 nanosec	1min06sec	1.91

Final remarks

- BIF is a tool intended for approximate designs
  → It’s generally a better solution than simple criteria like FAIL or MXEPS
- For detailed design: Sophisticated models like GISSMO, DIEM and eGISSMO are more appropriated
- BIF is available from LS-DYNA R16
- Recommendation: Calibrate EPSF for Le=0.5mm and then regularize it
- If in a hurry: Just calibrate EPSF for the target mesh size

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