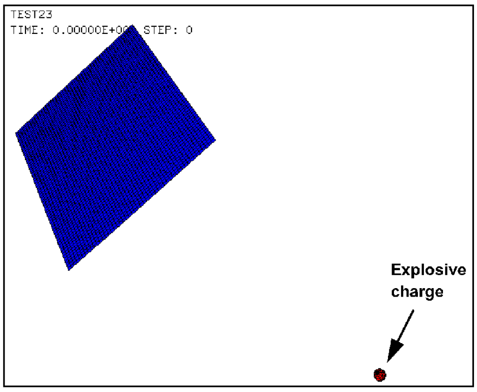
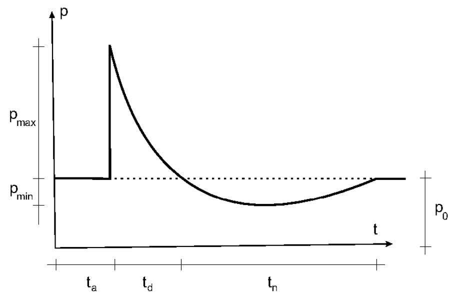
Exercise 15 – Blast on a glass sheet

Simulate the fragmentation of a glass sheet subjected to a blast wave using the AIRB model



Geometry



Pressure (AIRB)

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PROBLEM:
A fragile glass sheet is hit by a an explosive blast wave and fails, generating a cloud of fragments.
MESH:
The sheet is meshed by Q4GS 4-node shell elements. The blast pressure wave is applied to the sheet by means of CL3Q boundary condition elements. A PMAT element is used to visualize the initial position of the explosive charge, and 4 FUN3 elements are used to visualize the external frame of the sheet, which is held fixed.
GEOMETRIC COMPLEMENTS
Debris elements (DEBR) are associated with the whole sheet. By using PLEV 0, just one spherical particle replaces each failing shell element.
MATERIALS:
The glass sheet uses a linear elastic material (VM23) with an associated failure criterion (FAIL PEPR). A special impedance material IMPE AIRB is associated with the CL3Q elements that are used to apply the blast pressure wave to the sheet. A phantom (FANT) material is associated with the FUN3 elements used to visualize the frame.
BOUNDARY CONDITIONS:
The sheet is clamped all around its perimeter.
LOADING:
AIRB pressure loading is applied.
CALCULATIONS:
A calculation is performed until a physical time of 3 ms, when the sheet is completely failed.
RESULTS:
The sheet fragments as expected. Some macro fragments survive until the end of the simulation, together with a cloud of DEBR particles.

POST-TREATMENT

Animations are produced.

<u>Numerical Solutions</u>

TEST23

The Cast3m mesh generation file reads:

```
OPTI echo 1;
opti titr 'test23';
OPTI sauv form 'test23.msh';
opti trac psc ftra 'test23.ps';
OPTI dime 3 elem qua4;
den=0.02;
DENS den;
sizx = 1.00;
sizy = 1.40;
p0 = 0 0 0;
p1 = sizx 0 0;
p2 = sizx sizy 0;
p3 = 0 sizy 0;
pairb = 0.5 0.7 -3.5;
glas = (dall (p0 d p1) (p1 d p2) (p2 d p3) (p3 d p0) plan) coul bleu;
pres = glas coul roug;
!pres = (dall (p0 d p3) (p3 d p2) (p2 d p1) (p1 d p0) plan) coul bleu;
e0 = pres elem cont p0;
e1 = pres elem cont p1;
e2 = pres elem cont p2;
e3 = pres elem cont p3;
tple = e0 et e1 et e2 et e3;
lbq = p0 d p1 d p2 d p3 d;
fram = p0 d 1 p1 d 1 p2 d 1 p3 d 1 p0;
bubb = (manu poi1 pairb) coul roug;
mesh = glas et lbq et pres et bubb et tple et fram;
elim mesh;
TASS mesh;
sauv form mesh;
trac qual mesh;
*
list(nbno glas);
list(nbel glas);
list(nbno pres);
list(nbel pres);
list(nbno bubb);
list(nbel bubb);
list(nbno mesh);
list(nbel mesh);
fin;$
```

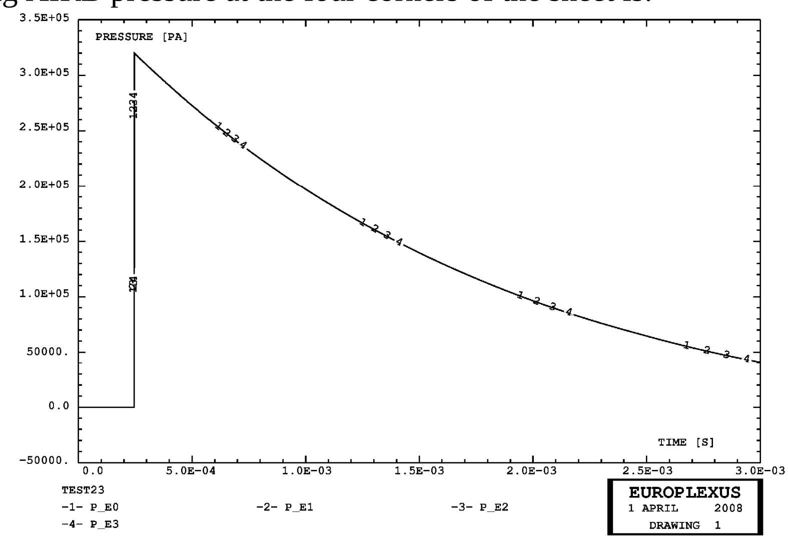
The EUROPLEXUS input file reads:

```
TEST23
ECHO
!CONV win
TRID LAGR FAIL 0.0
CAST FORM mesh
DIME
  PT6L 3622 PT3L 3500 Q4GS 3500 CL3Q 3500 PMAT 1 FUN3 4 DEBR 3500 ZONE 5
  FORC 100
  TABL 1 3
  PRES 33 26
TERM
GEOM
  Q4GS glas
  PMAT bubb
  FUN3 fram
  CL3Q pres
TERM
COMP EPAI 1.E-4 LECT glas TERM
          1.E-1 LECT bubb TERM
          1.E-4 LECT fram TERM
     DEBR ROF 1.0
          FILL PLEV 0
               RO 2500. DRAG 1.D0 TRAJ OBJE LECT glas TERM
     GROU 1 'part' LECT 7006 PAS 1 10505 TERM
     COUL roug LECT part  TERM
MATE VM23 RO 2500 YOUN 7E10 NU 0.23 ELAS 1.756E10
          FAIL PEPR LIMI 0.1
          TRAC 2 1.756E10 0.15 1.8E10 1.15
          LECT glas TERM
!    IMPE AIRB X 0.5 Y 0.7 Z -3.5 MASS 3 TINT -2.E-3
     IMPE AIRB NODE LECT bubb TERM MASS 3 TAUT
          LECT pres TERM
     MASS 1.0 LECT bubb TERM
     FANT 1.0 LECT fram TERM
LINK COUP FREQ 1
     BLOQ 123456 LECT lbq TERM
ECRI DEPL VITE TFRE 3.E-3
     FICH ALIC TEMP FREQ 1
          ELEM LECT tple TERM
     FICH SPLI ALIC TFRE 3.D-5
OPTI NOTE CSTA 0.5 LOG 1
CALC TINI 0. TEND 3.D-3
Fin
```

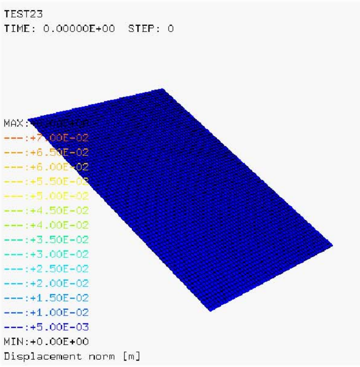
The EUROPLEXUS post-treatment file reads:

```
Post-treatment
ECHO
*
RESU SPLI ALIC 'test23.ali' GARD PSCR
COMP GROU 1 'part' LECT 7006 PAS 1 10505 TERM
*
SORT VISU NSTO 1
*=================================================================
PLAY
CAME   1 EYE  -2.51740E+00 -1.05337E+00  2.51415E+00
!        Q     8.50710E-01  3.34786E-01 -3.09280E-01 -2.61834E-01
         VIEW  7.01532E-01  4.07651E-01 -5.84529E-01
         RIGH  6.71577E-01 -6.52575E-01  3.50899E-01
         UP    2.38404E-01  6.38723E-01  7.31571E-01
         FOV   2.48819E+01
CAME   2 EYE   1.35836E+00 -3.40898E+00  2.68476E+00
!        Q     8.56960E-01  3.69966E-01  2.05747E-01 -2.93961E-01
         VIEW -1.35123E-01  7.55055E-01 -6.41587E-01
         RIGH  7.42511E-01 -3.51586E-01 -5.70145E-01
         UP    6.56064E-01  5.53425E-01  5.13129E-01
         FOV   2.48819E+01
SCEN GEOM NAVI FREE
          FACE SBAC
          POIN SPHP
     ISO  FILL FIEL DEPL SCAL USER PROG 0.5E-2 PAS 0.5E-2 7.E-2 TERM
     VECT SCCO FIEL VITE SCAL USER PROG 40. PAS 40. 560. TERM
     TEXT ISCA
     TEXT VSCA
     COLO PAPE
     LIMA ON
SLER CAM1 1 NFRA 1
FREQ 1
TRAC OFFS FICH AVI NOCL NFTO 101 FPS 10 KFRE 10 COMP -1
  OBJE NFAI LECT glas part fram TERM REND
GOTR LOOP 99 OFFS FICH AVI CONT NOCL
  OBJE NFAI LECT glas part fram TERM REND
GO
TRAC OFFS FICH AVI CONT
  OBJE NFAI LECT glas part fram TERM REND
ENDPLAY
*=================================================================
SUIT
Post-treatment (time curves from alice temps file)
ECHO
*
RESU ALIC TEMP 'test23.alt' GARD PSCR
*
SORT GRAP
*
AXTE 1.0 'Time [s]'
*
COUR 1 'p_e0' ECRO COMP 1 ELEM LECT e0 TERM
COUR 2 'p_e1' ECRO COMP 1 ELEM LECT e1 TERM
COUR 3 'p_e2' ECRO COMP 1 ELEM LECT e2 TERM
COUR 4 'p_e3' ECRO COMP 1 ELEM LECT e3 TERM
TRAC 1 2 3 4 AXES 1.0 'Pressure [Pa]'
FIN
```

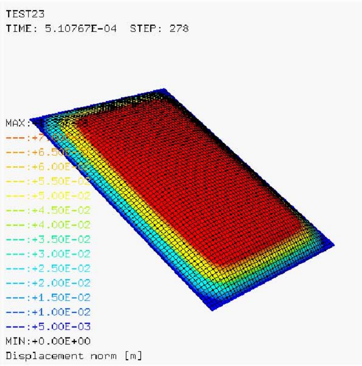
The resulting AIRB pressure at the four corners of the sheet is:



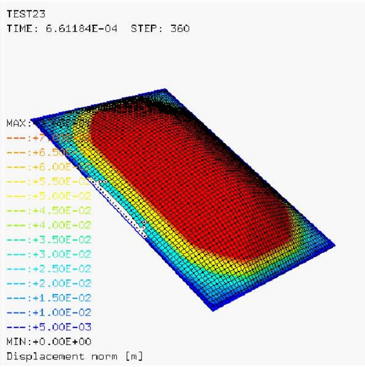
The fragmentation process and the velocities are shown in the next figures:



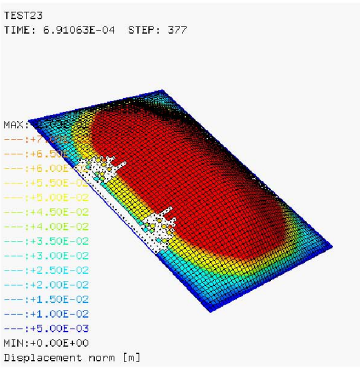
t = 0



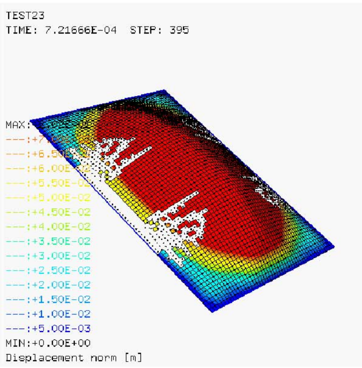
t = 0.50 ms



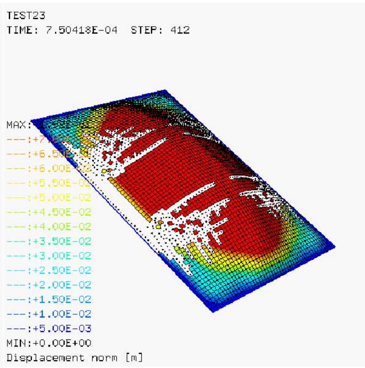
t = 0.66 ms



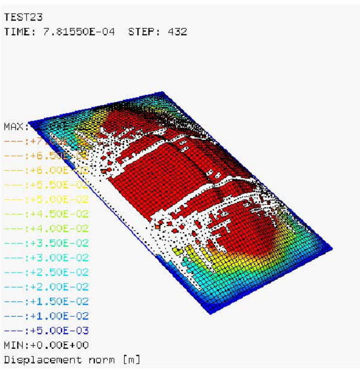
t = 0.69 ms



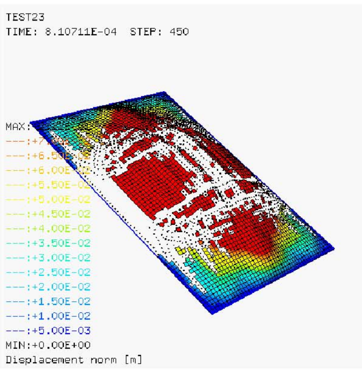
t = 0.72 ms



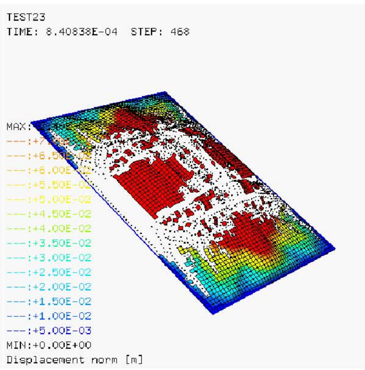
t = 0.75 ms



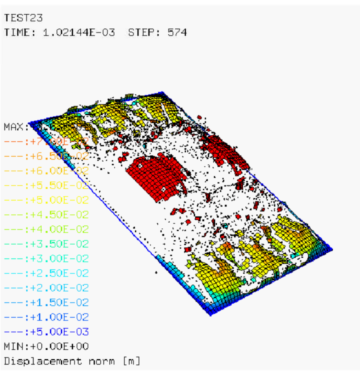
t = 0.78 ms



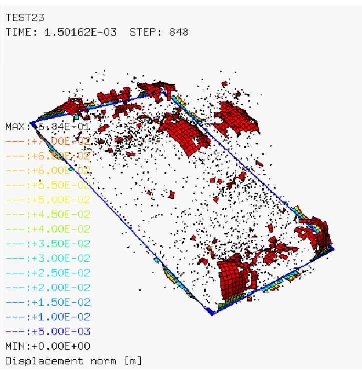
t = 0.81 ms



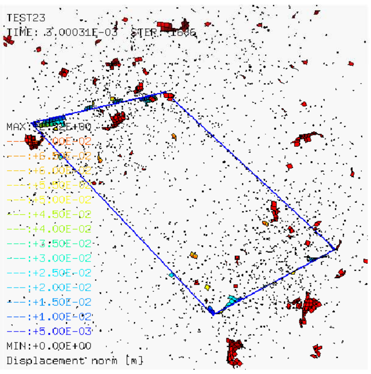
t = 0.84 ms



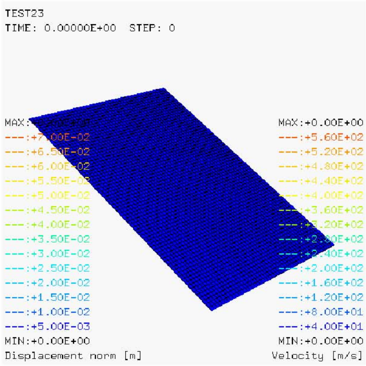
t = 1.02 ms



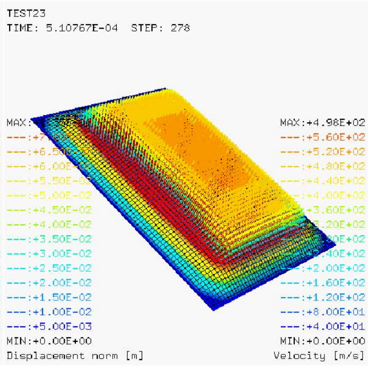
t = 1.50 ms



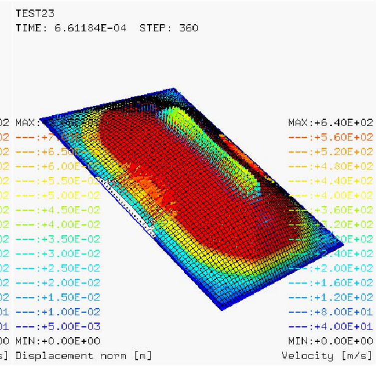
t = 3.00 ms



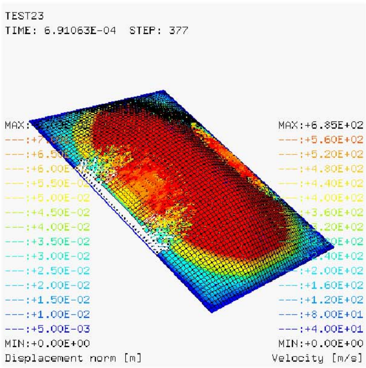
t = 0



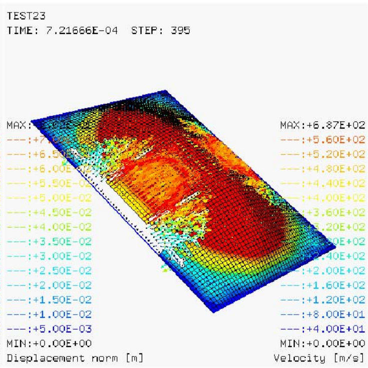
t = 0.50 ms



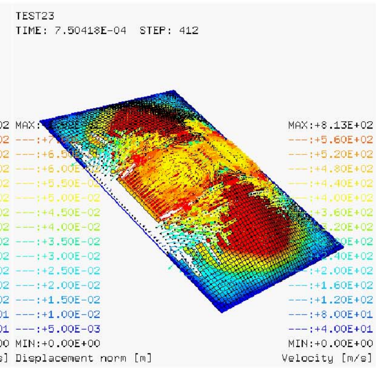
t = 0.66 ms



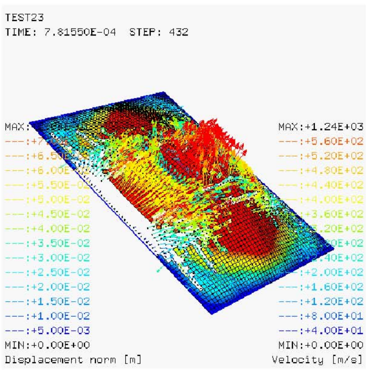
t = 0.69 ms



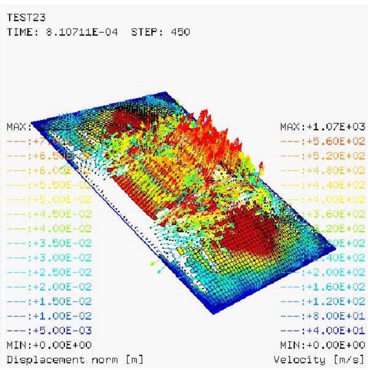
t = 0.72 ms



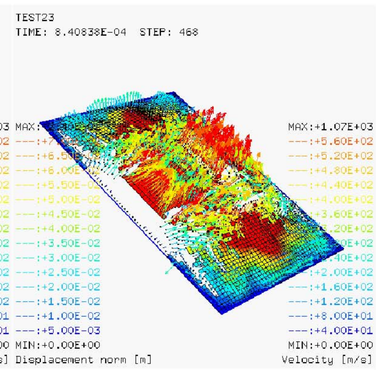
t = 0.75 ms



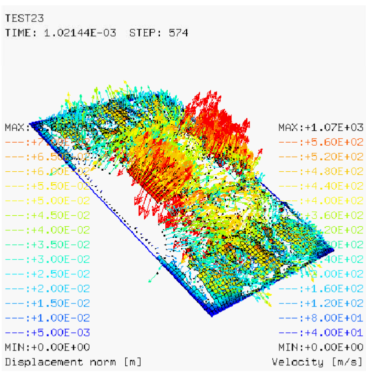
t = 0.78 ms



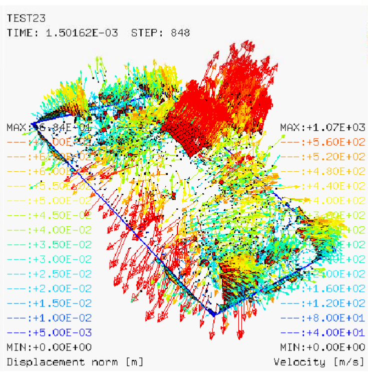
t = 0.81 ms



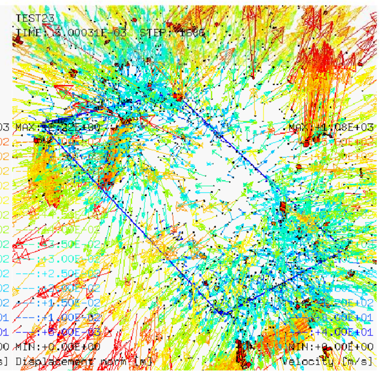
t = 0.84 ms



t = 1.02 ms



t = 1.50 ms

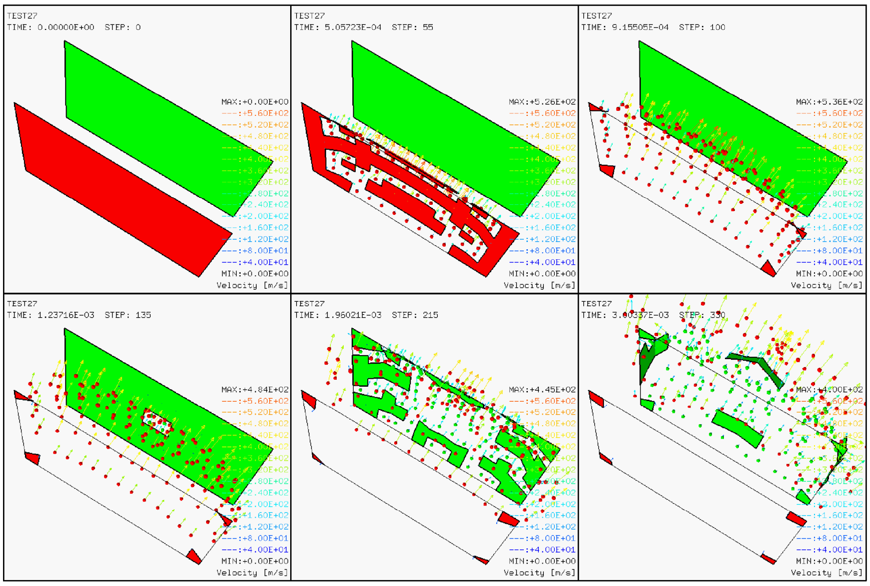


t = 3.00 ms

Formation of secondary debris

Exercise 15b – Secondary debris

Simulate the formation of secondary debris due to impact of primary debris on a glass sheet :



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A glass sheet is loaded by an air blast wave and breaks up into fragments (debris particles). These particles impact a second glass sheet nearby and break it up into secondary debris particles.

TEST27

The Cast3m mesh generation file reads:

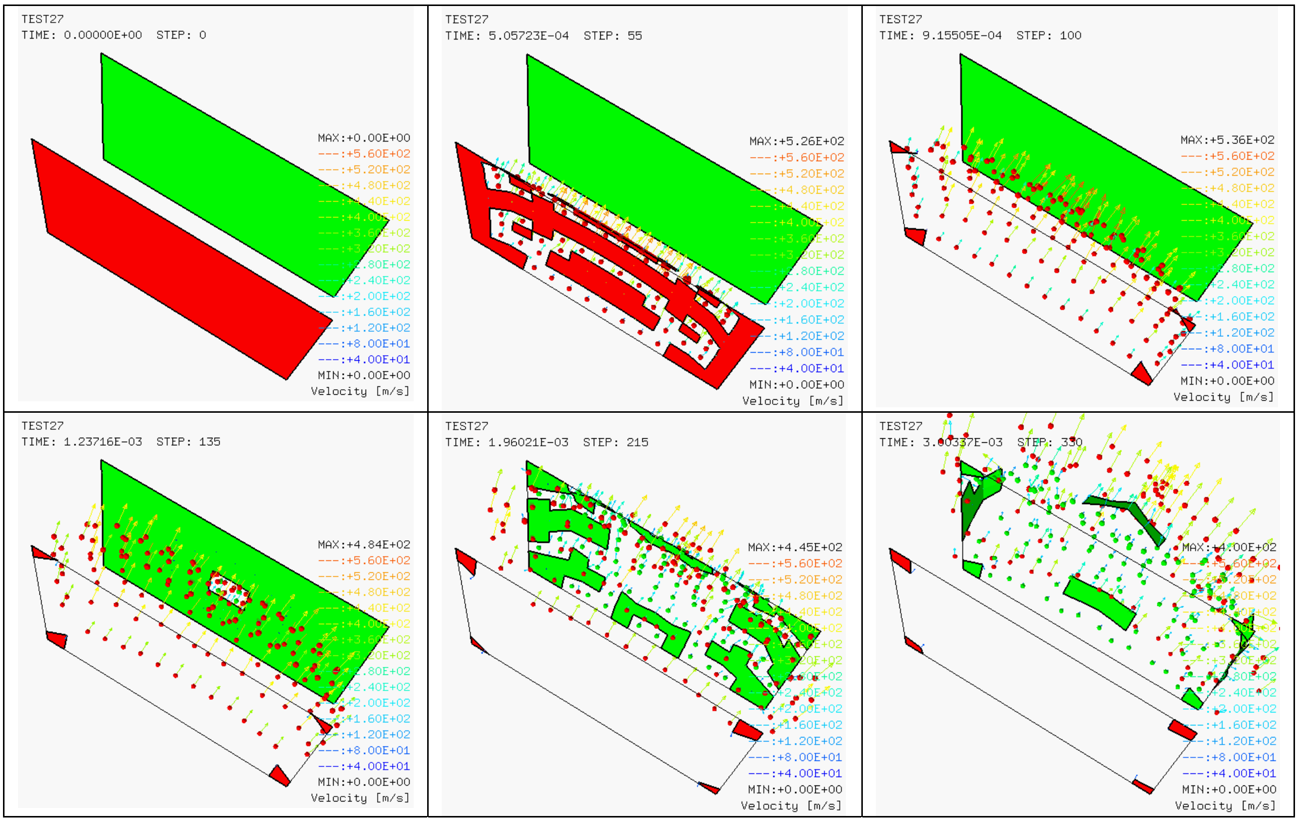
```
OPTI echo 1;
opti titr 'test27';
OPTI sauv form 'test27.msh';
opti trac psc ftra 'test27_mesh.ps';
OPTI dime 3 elem qua4;
den=0.10;
DENS den;
sizx = 1.00;
sizy = 1.40;
p0 = 0 0 0;
p1 = sizx 0 0;
p2 = sizx sizy 0;
p3 = 0 sizy 0;
pairb = 0.5 0.7 -3.5;
glas = (dall (p0 d p1) (p1 d p2) (p2 d p3) (p3 d p0) plan) coul roug;
glas2 = (glas plus (0 0 0.5)) coul vert;
pres = glas coul jaun;
e0 = pres elem cont p0;
e1 = pres elem cont p1;
e2 = pres elem cont p2;
e3 = pres elem cont p3;
tple = e0 et e1 et e2 et e3;
lbq = p0 d p1 d p2 d p3 d;
lbq = lbq et (cont glas2);
fram = p0 d 1 p1 d 1 p2 d 1 p3 d 1 p0;
fram = fram et (fram plus (0 0 0.5));
bubb = (manu poi1 pairb) coul roug;
mesh = glas et glas2 et lbq et pres et bubb et tple et fram;
elim mesh;
TASS mesh;
sauv form mesh;
trac qual mesh;
*
list(nbno glas);
list(nbel glas);
list(nbno glas2);
list(nbel glas2);
list(nbno pres);
list(nbel pres);
list(nbno bubb);
list(nbel bubb);
list(nbno mesh);
list(nbel mesh);
fin;
```

The EUROPLEXUS input file reads:

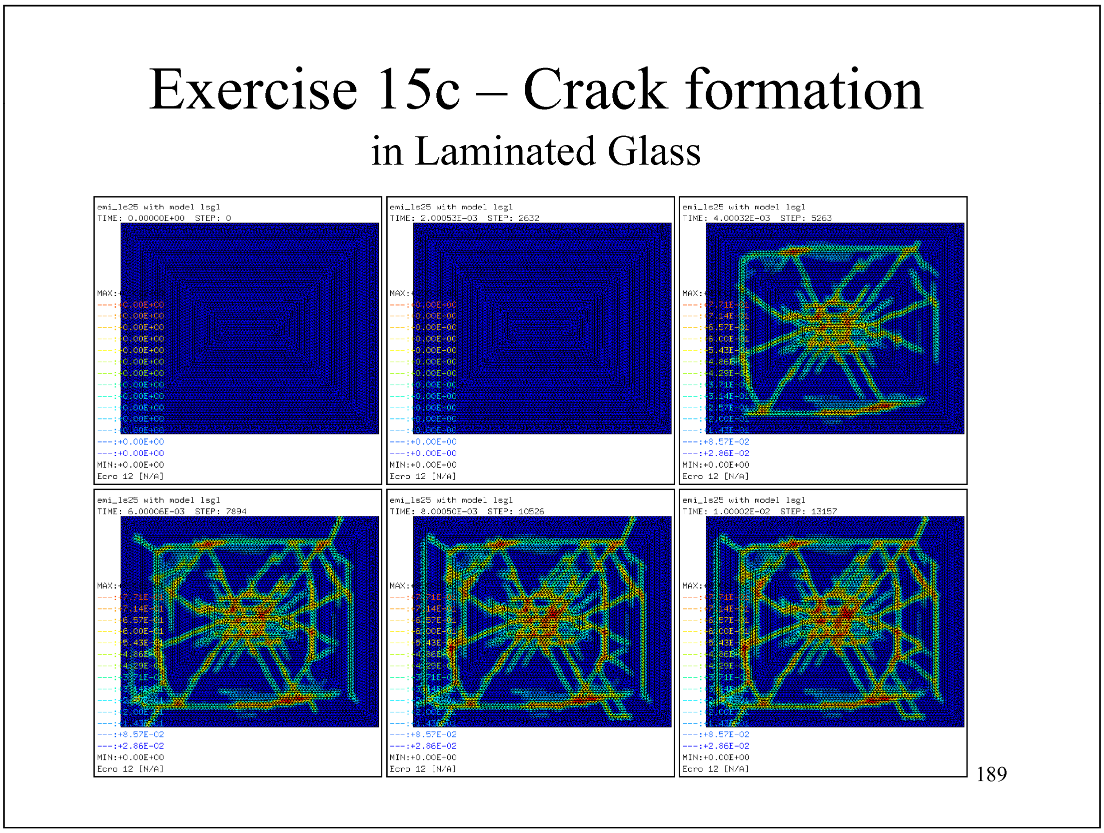
```
TEST27
ECHO
 CONV win
TRID LAGR EROS 0.0
CAST FORM mesh
DIME
  PT6L 330 PT3L 289 Q4GS 280 CL3Q 140 PMAT 1 FUN3 8 DEBR 280 ZONE 5
TERM
GEOM
  Q4GS glas glas2
  PMAT bubb
  FUN3 fram
  CL3Q pres
TERM
COMP EPAI 1.E-4 LECT glas glas2 TERM
          1.E-1 LECT bubb TERM
          1.E-4 LECT fram TERM
     DEBR ROF 1.0
          FILL PLEV 0
               RO 2500. DRAG 1.D0 TRAJ OBJE LECT glas TERM
          FILL PLEV 0
               RO 2500. DRAG 1.D0 TRAJ OBJE LECT glas2 TERM
     GROU 3 'part1' LECT 430 PAS 1 569 TERM
            'part2' LECT 570 PAS 1 709 TERM
            'part'  LECT part1 part2   TERM
     COUL roug LECT part1 TERM
          vert LECT part2 TERM
MATE VM23 RO 2500 YOUN 7E10 NU 0.23 ELAS 1.756E10
         !FAIL PEPR LIMI 0.1
          FAIL PEPR LIMI 0.05
          TRAC 2 1.756E10 0.15 1.8E10 1.15
          LECT glas glas2 TERM
     IMPE AIRB NODE LECT bubb TERM MASS 3 TAUT
          LECT pres TERM
     MASS 1.0 LECT bubb TERM
     FANT 1.0 LECT fram TERM
LINK COUP FREQ 1
     BLOQ 123456 LECT lbq TERM
     PINB BODY         DMIN 0.02 LECT glas2 TERM
          BODY MLEV 0 DIAM 0.02 LECT part1 TERM
```

```
ECRI DEPL VITE TFRE 3.E-3
     FICH ALIC FREQ 1
OPTI NOTE CSTA 0.5 LOG 1
CALC TINI 0. TEND 3.D-3
*=================================================================
PLAY
CAME   1 EYE  -3.25928E+00  1.61671E-01 -1.27078E+00 ! From below
!        Q     5.00268E-01  4.44242E-01 -7.09366E-01 -2.21768E-01
         VIEW  9.06783E-01  1.29851E-01  4.01102E-01
         RIGH -1.04761E-01 -8.52147E-01  5.12708E-01
         UP   -4.08374E-01  5.06935E-01  7.59109E-01
         FOV   2.48819E+01
SCEN GEOM NAVI FREE
          FACE SBAC
          LINE HEOU SFRE
          POIN SPHP FACT 2.0
          PINB CDES
     VECT SCCO FIEL VITE SCAL USER PROG 40. PAS 40. 560. TERM
     TEXT VSCA
     COLO PAPE
     LIMA ON
          LIGY -1
         !SELE BRAS
         !APPL MESH
SLER CAM1 1 NFRA 1
FREQ 1
TRAC OFFS FICH AVI NOCL NFTO 331 FPS 25 KFRE 10 COMP -1
     OBJE NFAI LECT glas glas2 part fram TERM REND
GOTR LOOP 329 OFFS FICH AVI CONT NOCL
     OBJE NFAI LECT glas glas2 part fram TERM REND
GO
TRAC OFFS FICH AVI CONT
     OBJE NFAI LECT glas glas2 part fram TERM REND
ENDPLAY
*=================================================================
FIN
```

The fragmentation process is shown in the next figure:



Crack formation in Laminated Glass



A laminated glass sheet is loaded by an air blast wave. After va certain time, cracks are formed whose pattern resembles the experimentally observed one.

EMI_LS25_DKT3

The Cast3m mesh generation file reads:

```
OPTI echo 1;
OPTI dime 3 elem tet4;
den=0.0125;
DENS den;
sizx = 1.1;
sizy = 0.9;
rand = 0.05;
b11 = rand rand 0;
b12 = (sizx-rand) rand 0;
b13 = (sizx-rand) (sizy-rand) 0;
b14 = rand (sizy-rand) 0;
li1 = b11 d b12 d b13 d b14 d;
a_airb = surf li1 plan;

b31 = 0 0 0;
b32 = sizx 0 0;
li3 = b31 d b32 d b12 d b11 d;
a3 = surf li3 plan;

b41 = sizx sizy 0;
li4 = b32 d b41 d b13 d b12 d;
a4 = surf li4 plan;

b51 = 0 sizy 0;
li5 = b41 d b51 d b14 d b13 d;
a5 = surf li5 plan;

li6 = b31 d b11 d b14 d b51 d;
a6 = surf li6 plan;

a_rand = a3 et a4 et a5 et a6;
a_glass1 = a_airb et a_rand;

p1 = 0 0 0.004;
p2 = 0 0 -0.004;
v1 = a_rand volu 'TRAN' p1;
v1 = v1 et (a_rand volu 'TRAN' p2);

pch1 = ((sizx+rand)/2.) ((sizy+rand)/2.) 1.8;
ch1 = manu poi1 pch1;

pcent = ((sizx+rand)/2.) ((sizy+rand)/2.) 0;

pdis = a_glass1 poin 'PROC' pcent;

edis1 = a_glass1 ELEM CONTENANT pdis;

a_v1 = v1 enve;

kod1 = faux;
REPE I0 (NBEL (a_v1 ELEM TRI3));
  xx yy zz = coor (bary (a_v1 ELEM TRI3 &I0));
  SI ( zz ega 0.004 0.001);
     si (kod1);bound=bound et (a_v1 ELEM TRI3 &I0);
     sinon; bound = a_v1 ELEM TRI3 &I0;kod1 = vrai;
     fins;
  FINS;
  SI ( zz ega -0.004 0.001);
     si (kod1);bound=bound et (a_v1 ELEM TRI3 &I0);
     sinon; bound = a_v1 ELEM TRI3 &I0;kod1 = vrai;
     fins;
  FINS;
FIN I0;


modell = v1 et a_glass1 et a_airb et pdis et
         edis1 et ch1 et bound;
elim modell;

TASS modell;
OPTI sauv form 'emi_ls25_dkt3.msh';
sauv form modell;
```

The EUROPLEXUS input file reads:

```
emi_ls25 with model lsgl
$
 ECHO
! VERI
! CONV WIN
CAST modell
TRID LAGR EROS 1.0
OPTI TOLC 1e-1
$
DIME
  PT6L        12000      ZONE  4
  PR6          5708      CL3T        14808     DKT3  14808
  PMAT 1
  ECRO      3373653
  LIAI        10400
  BLOQ        10400
  MNTI 102
  NGPZ 5
```

```
TERM
$
GEOM
  PR6 v1
  DKT3 a_glass1
  PMAT ch1
  CL3T a_airb
TERM
$
COMP
 EPAI 0.0075 LECT a_glass1 TERM
      0.05 LECT ch1 TERM ! only for visualization
 SAND    3
  FRAC 0.4 0.2 0.4
  NGPZ   2 1 2
  LECT a_glass1 term
 COUL roug LECT ch1 TERM
      turq LECT a_glass1 TERM
      jaun LECT a_airb TERM
      vert LECT v1 TERM
MATE
      LSGL RO 2500 YOUN 7E10 NU 0.23 CORR 16.0
           FAIL PEPR LIMI 0.0012
           LECT a_glass1 TERM
           laye lect 1 3 term
      VM23 RO 1100. YOUNG 3E6 NU 0.46 ELAS 3.45E9
           TRAC 1 3.45E9 15
           LECT a_glass1 TERM
           laye lect 2 term
      VM23 RO 2770. YOUNG 3.5e6 NU 0.42 ELAS 3.45E9
           TRAC 1 3.45E9 0.15
           LECT v1 TERM
      IMPE AIRB NODE LECT ch1 TERM CONF 1 MASS 0.09 TAUT
           LECT a_airb TERM
      FANT 1.E-3 LECT ch1 TERM
LIAI BLOQ 123 bound

ECRI DEPL VITE TFRE 5.E-3
     FICH SPLI ALIC tfreq 1e-4
     FICH ALIC TEMP tfreq 5e-5
               POIN LECT pdis TERM
               ELEM LECT 4148 1628 1698 edis1 TERM
$
OPTI NOTE LOG 1
$
CALC TINI 0 TEND 10e-3
*=================================================================
SUIT
Post-treatment (time curves from alice temps file)
ECHO
*
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'sig_edis' CONT COMP 1 GAUZ 0 ELEM LECT 4148 TERM
COUR 2 'sig_edis' CONT COMP 2 GAUZ 0 ELEM LECT 4148 TERM
COUR 3 'sig_edis' ECRO COMP 12 GAUZ 0 ELEM LECT 4148 TERM
COUR 4 'sig_edis' ECRO COMP 9 GAUZ 0 ELEM LECT 4148 TERM
COUR 5 'sig_edis' ECRO COMP 4 GAUZ 0 ELEM LECT 4148 TERM
COUR 6 'sig_edis' ECRO COMP 5 GAUZ 0 ELEM LECT 4148 TERM
COUR 7 'sig_edis' ECRO COMP 8 GAUZ 0 ELEM LECT 4148 TERM
COUR 11 'sig_edis' CONT COMP 1 GAUZ 0 ELEM LECT 1628 TERM
COUR 12 'sig_edis' CONT COMP 2 GAUZ 0 ELEM LECT 1628 TERM
COUR 13 'sig_edis' ECRO COMP 12 GAUZ 0 ELEM LECT 1628 TERM
COUR 14 'sig_edis' ECRO COMP 9 GAUZ 0 ELEM LECT 1628 TERM
COUR 15 'sig_edis' ECRO COMP 4 GAUZ 0 ELEM LECT 1628 TERM
COUR 16 'sig_edis' ECRO COMP 5 GAUZ 0 ELEM LECT 1628 TERM
COUR 17 'sig_edis' ECRO COMP 8 GAUZ 0 ELEM LECT 1628 TERM
COUR 21 'sig_edis' CONT COMP 1 GAUZ 0 ELEM LECT 1698 TERM
COUR 22 'sig_edis' CONT COMP 2 GAUZ 0 ELEM LECT 1698 TERM
COUR 23 'sig_edis' ECRO COMP 12 GAUZ 0 ELEM LECT 1698 TERM
COUR 24 'sig_edis' ECRO COMP 9 GAUZ 0 ELEM LECT 1698 TERM
COUR 25 'sig_edis' ECRO COMP 4 GAUZ 0 ELEM LECT 1698 TERM
COUR 26 'sig_edis' ECRO COMP 5 GAUZ 0 ELEM LECT 1698 TERM
COUR 27 'sig_edis' ECRO COMP 8 GAUZ 0 ELEM LECT 1698 TERM
COUR 9 SOMME 3 5 1 6 1 7 1
COUR 19 SOMME 3 15 1 16 1 17 1
COUR 29 SOMME 3 25 1 26 1 27 1
COUR 99 'dz_pdis' DEPL COMP 3 NOEU LECT pdis TERM
trac 1 2  axes 1.0 'SIG'
trac 9  axes 1.0 'EPSHYD'
trac 3 4  axes 1.0 'FAIL'
trac 11 12  axes 1.0 'SIG'
trac 19  axes 1.0 'EPSHYD'
trac 13 14  axes 1.0 'FAIL'
trac 21 22  axes 1.0 'SIG'
trac 29  axes 1.0 'EPSHYD'
trac 23 24  axes 1.0 'FAIL'
trac 99 text axes 1.0 'DISPL. [M]'
SUIT
*=================================================================
emi12_avi
 ECHO
 CONV WIN
RESU SPLI ALIC GARD PSCR
*
OPTI PRIN
*
SORT VISU NSTO 1
*=================================================================
PLAY
CAME   1 EYE   5.00000E-01  4.00000E-01  6.42268E+00
!        Q     1.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
         VIEW  0.00000E+00  0.00000E+00 -1.00000E+00
         RIGH  1.00000E+00  0.00000E+00  0.00000E+00
         UP    0.00000E+00  1.00000E+00  0.00000E+00
         FOV   1.08819E+01
SCEN GEOM NAVI FREE
          FACE SBAC
          POIN SPHP
     ISO  FILL FIEL ECRO 12 SCAL A14
     TEXT ISCA
     COLO PAPE
sler cam1 1        nfra 1
freq 200
go
trac offs fich bmp
     obje lect a_glass1 term   rend
ENDPLAY
*=================================================================
FIN
```

The cracking process is shown in the next figure: