**Modeling**

new

def parameter\_setup

domain\_min=-75

domain\_max=75

wall\_length=50

x=wall\_length

y=wall\_length

z=wall\_length

end

@parameter\_setup

; 设置域范围

domain extent [domain\_min] [domain\_max]

domain condition destroy

cmat default model linear method deformability emod 1.0e9 kratio 0.0

cmat default property dp\_nratio 0.5

; 创建延伸超过样本边缘的墙

wall generate id 1 polygon ...

[-x] [-y] [z] ...

[-x] [y] [z] ...

[-x] [y] [-z] ...

[-x] [-y] [-z];back side

wall generate id 2 polygon ...

[x] [-y] [z] ...

[x] [y] [z] ...

[x] [y] [-z] ...

[x] [-y] [-z];front side

wall generate id 3 polygon ...

[-x] [-y] [z] ...

[x] [-y] [z] ...

[-x] [-y] [-z] ...

[x] [-y] [-z];left side

wall generate id 4 polygon ...

[-x] [y] [z] ...

[x] [y] [z] ...

[-x] [y] [-z] ...

[x] [y] [-z];right side

wall generate id 5 polygon ...

[x] [-y] [z] ...

[x] [y] [z] ...

[-x] [-y] [z] ...

[-x] [y] [z];up side

wall generate id 6 polygon ...

[x] [-y] [-z] ...

[x] [y] [-z] ...

[-x] [-y] [-z] ...

[-x] [y] [-z];down side

set random 10002

ball distribute porosity 0.05 ...

box -50 50 ...

numbin 6 ...

bin 1 ...

radius 3.6 ...

volumefraction 0.204 ...

group cement ...

bin 2 ...

radius 1.7 ...

volumefraction 0.020 ...

group waterreducer ...

bin 3 ...

radius 1.6 ...

volumefraction 0.017 ...

group silicafume ...

bin 4 ...

radius 2.4 ...

volumefraction 0.056 ...

group flyash ...

bin 5 ...

radius 5.5 ...

volumefraction 0.687 ...

group sand ...

bin 6 ...

radius 1.6 ...

volumefraction 0.016 ...

group steelfiber

ball attribute density 3100 range group cement

ball attribute density 1152 range group waterreducer

ball attribute density 2350 range group silicafume

ball attribute density 2100 range group flyash

ball attribute density 1400 range group sand

ball attribute density 7800 range group steelfiber

ball attribute damp 0.7

;使墙体扩大

def wall\_wp

global wpz1 = wall.find(1)

global wpz2 = wall.find(2)

global wpz3 = wall.find(3)

global wpz4 = wall.find(4)

global wpz5 = wall.find(5)

global wpz6 = wall.find(6)

end

@wall\_wp

define extend\_walls(fac0)

loop foreach local vertex wall.vertexlist(wpz1)

wall.vertex.pos.y(vertex) = fac0\*wall.vertex.pos.y(vertex)

wall.vertex.pos.z(vertex) = fac0\*wall.vertex.pos.z(vertex)

endloop

loop foreach vertex wall.vertexlist(wpz2)

wall.vertex.pos.y(vertex) = fac0\*wall.vertex.pos.y(vertex)

wall.vertex.pos.z(vertex) = fac0\*wall.vertex.pos.z(vertex)

endloop

loop foreach vertex wall.vertexlist(wpz3)

wall.vertex.pos.x(vertex) = fac0\*wall.vertex.pos.x(vertex)

wall.vertex.pos.z(vertex) = fac0\*wall.vertex.pos.z(vertex)

endloop

loop foreach vertex wall.vertexlist(wpz4)

wall.vertex.pos.x(vertex) = fac0\*wall.vertex.pos.x(vertex)

wall.vertex.pos.z(vertex) = fac0\*wall.vertex.pos.z(vertex)

endloop

loop foreach vertex wall.vertexlist(wpz5)

wall.vertex.pos.x(vertex) = fac0\*wall.vertex.pos.x(vertex)

wall.vertex.pos.y(vertex) = fac0\*wall.vertex.pos.y(vertex)

endloop

loop foreach vertex wall.vertexlist(wpz6)

wall.vertex.pos.x(vertex) = fac0\*wall.vertex.pos.x(vertex)

wall.vertex.pos.y(vertex) = fac0\*wall.vertex.pos.y(vertex)

endloop

end

@extend\_walls(1.5)

save model0

; 让系统平静下来

cycle 1000 calm 10

; 将系统求解到目标极限（此处为平均力比）

; 使用密度缩放快速达到平衡

set timestep scale

solve aratio 1e-4

set timestep auto

calm

; 添加一个测量圆以记录应力

measure create id 1 position 0 0 0 radius 25

def ini\_mstrains

global mp = measure.find(1)

global mstrains = matrix(3,3)

end

; 记录历史

history id 1 measure stressxx id 1

history id 2 measure stressyy id 1

history id 3 measure stresszz id 1

save model1

contact model linearpbond range contact type ball-ball

contact method bond gap 2.0e-4

; 使用方法设置线性刚度

contact method deform emod 1.0e9 krat 1.0

; 用方法设置粘结刚度

contact method pb\_deform emod 1.0e9 krat 1.0

;设定粘合强度

contact property pb\_ten 10.0e6 pb\_coh 50.0e6 pb\_fa 0.0

; 在触点处设置一些阻尼

contact property dp\_nratio 0.5

; 将钢球摩擦力设置为非零值

contact property fric 0.577 range contact type ball-ball

; 重置球位移

ball attribute displacement multiply 0.0

; 将线性力设置为0.0，并强制重置线性接触力。

contact property lin\_force 0.0 0.0 0.0 lin\_mode 1

ball attribute contactforce multiply 0.0 contactmoment multiply 0.0

cycle 1

solve aratio 1e-5

save mode3

; 请注意包含关键字“墙”，否则方面将被删除

wall delete walls range id 1 4

save mode2

**Compress**

restore model2

; 设置应力应变测量的全局参数

define setup\_wall

global wp\_top = wall.find(5)

global wp\_bottom = wall.find(6)

global vertical\_direction = global.dim

global sample\_height = wall.pos(wp\_top,vertical\_direction) - wall.pos(wp\_bottom,vertical\_direction)

local xmin = 1.0e12

local xmax = -1.0e12

loop foreach bp ball.list

local ball\_xmin = ball.pos.x(bp) - ball.radius(bp)

xmin = math.min(xmin,ball\_xmin)

local ball\_xmax = ball.pos.x(bp) + ball.radius(bp)

xmax = math.max(xmax,ball\_xmax)

end\_loop

local diameter\_ = xmax - xmin

if global.dim = 2

global cross\_sectional\_area = diameter\_

else

cross\_sectional\_area = math.pi\*0.25\*diameter\_\*diameter\_

end\_if

end

@setup\_wall

; 通过移动顶壁和底壁施加荷载

wall attribute zvelocity -0.15 range id 5

wall attribute zvelocity 0.15 range id 6

; 施加少量阻尼

ball attribute damp 0.7

; 记录历史

define axial\_stress\_wall

local force1 = wall.force.contact(wp\_top,vertical\_direction)

local force2 = -wall.force.contact(wp\_bottom,vertical\_direction)

axial\_stress\_wall = 0.5\*(force1+force2)/cross\_sectional\_area

end

define axial\_strain\_wall

axial\_strain\_wall = -2.0\*wall.disp(wp\_top,vertical\_direction)/sample\_height

end

history id 4 @axial\_stress\_wall

history id 5 @axial\_strain\_wall

define add\_crack(entries)

local contact = entries(1)

local mode = entries(2)

local frac\_pos = contact.pos(contact)

local norm = contact.normal(contact)

local dfn\_label = 'crack'

local frac\_size

local bp1 = contact.end1(contact)

local bp2 = contact.end2(contact)

local ret = math.min(ball.radius(bp1),ball.radius(bp2));contact.method(contact,'pb\_radius')

frac\_size = ret

local arg = array.create(5)

arg(1) = 'disk'

arg(2) = frac\_pos

arg(3) = frac\_size

arg(4) = math.dip.from.normal(norm)/math.degrad

arg(5) = math.ddir.from.normal(norm)/math.degrad

if arg(5) < 0.0

arg(5) = 360.0+arg(5)

end\_if

crack\_num\_Total = crack\_num\_Total + 1

if mode = 1 then

; 张力/紧张失败

dfn\_label = dfn\_label + '\_tension'

crack\_num\_Tension = crack\_num\_Tension + 1

else if mode = 2 then

; 剪切失败

dfn\_label = dfn\_label + '\_shear'

crack\_num\_Shear = crack\_num\_Shear + 1

endif

global dfn = dfn.find(dfn\_label)

if dfn = null then

dfn = dfn.add(0,dfn\_label)

endif

local fnew = dfn.addfracture(dfn,arg)

dfn.fracture.prop(fnew,'age') = mech.age

dfn.fracture.extra(fnew,1) = bp1

dfn.fracture.extra(fnew,2) = bp2

crack\_accum += 1

if crack\_accum > 50

if frag\_time < mech.age

frag\_time = mech.age

crack\_accum = 0

command

fragment compute

endcommand

; 检查并更新断裂位置

loop for (local i = 0, i < 2, i = i + 1)

local name = 'crack\_tension'

if i = 1

name = 'crack\_shear'

endif

dfn = dfn.find(name)

if dfn # null

loop foreach local frac dfn.fracturelist(dfn)

local ball1 = dfn.fracture.extra(frac,1)

local ball2 = dfn.fracture.extra(frac,2)

if ball1 # null

if ball2 # null

local len = dfn.fracture.diameter(frac)/2.0

local pos = (ball.pos(ball1)+ball.pos(ball2))/2.0

if comp.x(pos)-len > xmin

if comp.x(pos)+len < xmax

if comp.y(pos)-len > ymin

if comp.y(pos)+len < ymax

if comp.z(pos)-len > zmin

if comp.z(pos)+len < zmax

dfn.fracture.pos(frac) = pos

end\_if

end\_if

endif

endif

endif

endif

endif

endif

endloop

endif

endloop

endif

endif

end

; 记录裂缝

define track\_init

command

dfn delete

ball result clear

fragment clear

fragment register ball-ball

endcommand

; 激活fishcalls

command

set fish callback bond\_break remove @add\_crack

set fish callback bond\_break @add\_crack

endcommand

; 重置全局变量

global crack\_accum = 0

global crack\_num\_Total = 0

global track\_time0 = mech.age

global frag\_time = mech.age

global xmin = domain.min.x()

global ymin = domain.min.y()

global xmax = domain.max.x()

global ymax = domain.max.y()

global zmin = domain.min.z()

global zmin = domain.min.z()

end

@track\_init

history id 6 @crack\_num\_Total

history id 7 @crack\_num\_Tension

history id 8 @crack\_num\_Shear

; 循环几步以完成初始飞行

cycle 1000

; 运行测试，直到压力降至峰值的70%以下

define loadhalt\_wall

loadhalt\_wall = 0

local abs\_stress = math.abs(axial\_stress\_wall)

global peak\_stress = math.max(abs\_stress,peak\_stress)

if abs\_stress < peak\_stress\*peak\_fraction

loadhalt\_wall = 1

end\_if

end

set @peak\_fraction = 0.7

solve fishhalt @loadhalt\_wall

list @peak\_stress

save after\_compress

**Plot**

; 绘图命令

plot create plot 'measure'

plot add hist 1

; y轴stress vs x轴strain

plot create plot 'axial\_stress\_wall vs axial\_strain\_wall'

plot add hist 4 vs 5

plot create plot 'crack\_num\_Total vs crack\_num\_Tension vs crack\_num\_Shear'

plot add hist 6 vs 7 vs 8

return

**Temperature**

;定义球体半径膨胀

def ball\_wp

local erp

global bpz1 = ball.find(cement)

global bpz2 = ball.find(waterreducer)

global bpz3 = ball.find(silicafume)

global bpz4 = ball.find(flyash)

global bpz5 = ball.find(sand)

global bpz6 = ball.find(steelfiber)

end

@ball\_wp

;erp=expand radius parameter

;t=times

def expand\_balls

local t

if t = 0

then erp == 1

else if t>0

then erp == (300+473.15\*t)\*5.5e-6

endif

t=5

loop foreach local radius ball.radius(bpz1)

ball.radius(radius) = erp\*ball.radius(radius)

endloop

loop foreach radius ball.radius(bpz2)

ball.radius(radius) = erp\*ball.radius(radius)

endloop

loop foreach radius ball.radius(bpz3)

ball.radius(radius) = erp\*ball.radius(radius)

endloop

loop foreach radius ball.radius(bpz4)

ball.radius(radius) = erp\*ball.radius(radius)

endloop

loop foreach radius ball.radius(bpz5)

ball.radius(radius) = erp\*ball.radius(radius)

endloop

loop foreach radius ball.radius(bpz6)

ball.radius(radius) = erp\*ball.radius(radius)

endloop

end

set fish callback 1.0 @expand\_balls

restore model3

;应变测量球

define ini\_mstrains

global mp = measure.find(1)

global mstrains = matrix(3,3)

end

@ini\_mstrains

define accumulate\_mstrains

global msrate = measure.strainrate.full(mp)

global mstrains = mstrains + msrate \* global.timestep

global xxmstrain = mstrains(1,1)

global yymstrain = mstrains(2,2)

global zzmstrain = mstrains(3,3)

end

set fish callback 1.0 @accumulate\_mstrains

history id 9 @xxmstrain

history id 10 @yymstrain

history id 11 @zzmstrain

ball attribute displacement multiply 0.0

wall attribute velocity multiply 0.0

define smxx

smxx = measure.stress.xx(mp)

end

define smyy

smyy = measure.stress.yy(mp)

end

define smzz

smzz = measure.stress.zz(mp)

end

[swxx0 = swxx]

[swyy0 = swyy]

[swzz0 = swzz]

[smxx0 = smxx]

[smyy0 = smyy]

[smzz0 = smzz]

define compute\_dsig

global dsmxx = smxx - smxx0

global dsmyy = smyy - smyy0

global dsmzz = smzz - smzz0

global dswxx = swxx - swxx0

global dswyy = swyy - swyy0

global dswzz = swzz - swzz0

end

@compute\_dsig

history id 12 @compute\_dsig

define add\_crack(entries)

local contact = entries(1)

local mode = entries(2)

local frac\_pos = contact.pos(contact)

local norm = contact.normal(contact)

local dfn\_label = 'crack'

local frac\_size

local bp1 = contact.end1(contact)

local bp2 = contact.end2(contact)

local ret = math.min(ball.radius(bp1),ball.radius(bp2));contact.method(contact,'pb\_radius')

frac\_size = ret

local arg = array.create(5)

arg(1) = 'disk'

arg(2) = frac\_pos

arg(3) = frac\_size

arg(4) = math.dip.from.normal(norm)/math.degrad

arg(5) = math.ddir.from.normal(norm)/math.degrad

if arg(5) < 0.0

arg(5) = 360.0+arg(5)

end\_if

crack\_num\_Total = crack\_num\_Total + 1

if mode = 1 then

; 张力/紧张失败

dfn\_label = dfn\_label + '\_tension'

crack\_num\_Tension = crack\_num\_Tension + 1

else if mode = 2 then

; 剪切失败

dfn\_label = dfn\_label + '\_shear'

crack\_num\_Shear = crack\_num\_Shear + 1

endif

global dfn = dfn.find(dfn\_label)

if dfn = null then

dfn = dfn.add(0,dfn\_label)

endif

local fnew = dfn.addfracture(dfn,arg)

dfn.fracture.prop(fnew,'age') = mech.age

dfn.fracture.extra(fnew,1) = bp1

dfn.fracture.extra(fnew,2) = bp2

crack\_accum += 1

if crack\_accum > 50

if frag\_time < mech.age

frag\_time = mech.age

crack\_accum = 0

command

fragment compute

endcommand

; 检查并更新断裂位置

loop for (local i = 0, i < 2, i = i + 1)

local name = 'crack\_tension'

if i = 1

name = 'crack\_shear'

endif

dfn = dfn.find(name)

if dfn # null

loop foreach local frac dfn.fracturelist(dfn)

local ball1 = dfn.fracture.extra(frac,1)

local ball2 = dfn.fracture.extra(frac,2)

if ball1 # null

if ball2 # null

local len = dfn.fracture.diameter(frac)/2.0

local pos = (ball.pos(ball1)+ball.pos(ball2))/2.0

if comp.x(pos)-len > xmin

if comp.x(pos)+len < xmax

if comp.y(pos)-len > ymin

if comp.y(pos)+len < ymax

if comp.z(pos)-len > zmin

if comp.z(pos)+len < zmax

dfn.fracture.pos(frac) = pos

end\_if

end\_if

endif

endif

endif

endif

endif

endif

endloop

endif

endloop

endif

endif

end

; 记录裂缝

define track\_init

command

dfn delete

ball result clear

fragment clear

fragment register ball-ball

endcommand

; 激活fishcalls

command

set fish callback bond\_break remove @add\_crack

set fish callback bond\_break @add\_crack

endcommand

; 重置全局变量

global crack\_accum = 0

global crack\_num\_Total = 0

global track\_time0 = mech.age

global frag\_time = mech.age

global xmin = domain.min.x()

global ymin = domain.min.y()

global xmax = domain.max.x()

global ymax = domain.max.y()

global zmin = domain.min.z()

global zmin = domain.min.z()

end

@track\_init

history id 6 @crack\_num\_Total

history id 7 @crack\_num\_Tension

history id 8 @crack\_num\_Shear

;wall delete

configure thermal

ball thermal attribute thexp 3e-3

ball thermal attribute sheat 10e3

ball thermal attribute temperature 0

ball thermal attribute deltemp 200

set thermal on mechanical on

cycle 1

set thermal off mechanical on

cycle 10

solve aratio 10

;solve aratio 1e-6

wall delete walls range id 1 4

save after\_heated

**Heated compress**

restore after\_heated

; 清除历史记录

history purge

; 设置应力应变测量的全局参数

define setup\_wall

global wp\_top = wall.find(5)

global wp\_bottom = wall.find(6)

global vertical\_direction = global.dim

global sample\_height = wall.pos(wp\_top,vertical\_direction) - wall.pos(wp\_bottom,vertical\_direction)

local xmin = 1.0e12

local xmax = -1.0e12

loop foreach bp ball.list

local ball\_xmin = ball.pos.x(bp) - ball.radius(bp)

xmin = math.min(xmin,ball\_xmin)

local ball\_xmax = ball.pos.x(bp) + ball.radius(bp)

xmax = math.max(xmax,ball\_xmax)

end\_loop

local diameter\_ = xmax - xmin

if global.dim = 2

global cross\_sectional\_area = diameter\_

else

cross\_sectional\_area = math.pi\*0.25\*diameter\_\*diameter\_

end\_if

end

@setup\_wall

; 通过移动顶壁和底壁施加荷载

wall attribute zvelocity -0.15 range id 5

wall attribute zvelocity 0.15 range id 6

; 施加少量阻尼

ball attribute damp 0.7

; 记录历史

define axial\_stress\_wall

local force1 = wall.force.contact(wp\_top,vertical\_direction)

local force2 = -wall.force.contact(wp\_bottom,vertical\_direction)

axial\_stress\_wall = 0.5\*(force1+force2)/cross\_sectional\_area

end

define axial\_strain\_wall

axial\_strain\_wall = -2.0\*wall.disp(wp\_top,vertical\_direction)/sample\_height

end

history id 4 @axial\_stress\_wall

history id 5 @axial\_strain\_wall

; 循环几步以完成初始飞行

cycle 200

; 运行测试，直到压力降至峰值的70%以下

define loadhalt\_wall

loadhalt\_wall = 0

local abs\_stress = math.abs(axial\_stress\_wall)

global peak\_stress = math.max(abs\_stress,peak\_stress)

if abs\_stress < peak\_stress\*peak\_fraction

loadhalt\_wall = 1

end\_if

end

;plot create plot 'measure stress vs measure strain'

;plot add hist 3 vs 11

set @peak\_fraction = 0.7

solve fishhalt @loadhalt\_wall

list @peak\_stress

save heated\_compress