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Strain rate influence on void closure in open die forging

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Abstract

This paper presents an investigation to the effect of the strain on healing voids that inhabit at various sizes in an ingot. The study was performed rate by using finite element deformation method with bilinear isotropic material option, circular type voids were considered. The closure index was able to predict the minimum press force necessary to consolidate voids and the reduction. The simulation was carried out, on circular cross-section lead specials containing a central void of different size. At a time with a flat die, different ratio of inside to outside radius was taken with different strain rates to find the best result of void closure.

الخلاصة

يقدم هذا البحث دراسة في تاثير معدل الأنفعال على غلق الفجوات بمختلف أحجامها في المصبوبات , وقد تم استخدام طريقة العناصر المحددة في التحليل وتمت عملية التمثيل لمقطع اسطواني لمصبوبة تحتوي على تجاويف مركزية مختلفة الأحجام . تم التحليل على اساس ثنائي الأبعاد باستخدام قالب طرق مفتوح , وتم الحصول على النتائج لأغراض االمقارنة وايجاد افضل انغلاق للفجوة باحجام مختلفة ومعدل انفعالات مختلفة .

Nomenclatures

A0	Initial area (m2)
Ai	Area at instance i (m2)
B	Strain displacement relationship matrix
B	Transpose of strain –displacement relation matrix
D	Material properties matrix
Dmax	Max – displacement
ET	Element type
E	Young's modulus (N/m2)
Fx/Fy	External applied faces (N)
K	Bulk modules (N/m2)
Ke	Stiffness matrix for element e
N	Number of nodes
Px,Py	Pressure in direction x & y (N/m2)
Pi	Pressure at instant i (N/m2)
Smin,Smax	Minimum & maximum stress
T	Thickens of the specimen (m)
T	Time (sec)
E	Strain vector
έ	Strain rate
S	Displacement vector (u1, v1, u2, v2, u3, v3, u4, v4) m
X	Functional
U	Total energy (joule)
Q	Unit matrix
σ_e	Equivalent stress (N/m

Introduction

Casting is the method used to shape bulk of engineering materials due to simplicity and possibility of casting large products. The defects in casting are shrinkage, gas porosity, hot tears, alloy segregation and inclusions [1]. The defects by solidification shrinkage and gas porosity are relatively different to control. The void formed in the product must be eliminated by the application of compression loads compatible with plastic deformation.

Forging is classified as closed die and open die forging. In closed die forging, a compressive force is applied on the work piece and forced to take the shape of the die surface or impression.

Open die forging is a processes used to produced huge turbine shafts, nuclear reactors, vessels and pressure value [2]. These parts should have good toughness and fatigue strength.

Most failures of engineering components can be initiated by concentration of stresses of internal microscopic voids or inclusions, therefore the strategy is to close and consolidate these internal defects completely.

Closure of voids and consolidation of internal defects is a very significant issue for some reasons like void constitutes the weakest portion of the component, and act as stress raisers, which promote fatigue.

The finite element method (FEM) is a comprehensive tool which is flexible and capable of tracing material flow and able to investigate contours of stresses and strain, even in cases of linear and non-linear material properties

Theoretical consideration and analysis

The efficient method of analysis for metal forming should be capable of predicting the effect of various parameters on metal flow characteristics [3].

In this regard, the rigid viscoplastic defect formation in metal forming.

In simulating, the void closure in forging the assumptions taken for the material and the process such as an isotropic and homogenous, rigid perfectly plastic, the friction between the work piece and the die is considered to obey coulomb friction low(sliding only), plane strain and isothermal process.

For (2D) finite element surface to surface analysis, Ansys software utilizes two distinct contact surfaces, the rigid surface referred to as" target" surfaces which is modeled with element type"targe 169"or the deformable body surface is referred as" contact" element type contact for 2D .

Large strain solid the element type visco 106 is used (four-node nonlinear solid).

For quadrilateral element, the displacements are interpolated as follows [4]:

$$u = \sum_{\tau=1}^{4} niui \text{ ---1}$$

$$v = \sum_{i=1}^{4} nivi \text{ ---2}$$

Strains are obtained from the displacements:-

$$\varepsilon_x = \frac{\partial_u}{\partial_x} = \sum_{i=1}^{4} \frac{\partial_{ni}}{\partial_x} ui \text{ --3}$$

$$\varepsilon_y = \frac{\partial_v}{\partial_x} = \sum_{i=1}^{4} \frac{\partial_{ni}}{\partial_y} vi \text{ --4}$$

$$\varepsilon_{xy} = \frac{\partial_u}{\partial_y} + \frac{\partial v}{\partial_x} = \sum_{i=1}^{4} \left(\frac{\partial_{ni}}{\partial_y} ui + \frac{\partial_{ni}}{\partial_x} vi \right) \text{ --5}$$

$$\underline{\varepsilon} = \begin{bmatrix} \frac{\partial_{n1}}{\partial_x} \; 0 \; \frac{\partial_{n2}}{\partial_x} \; 0 \; \frac{\partial_{n3}}{\partial_x} \; 0 \; \frac{\partial_{n4}}{\partial_x} \; 0 \\ 0 \; \frac{\partial_{n1}}{\partial_y} \; 0 \; \frac{\partial_{n2}}{\partial_y} \; 0 \; \frac{\partial_{n3}}{\partial_y} \; 0 \; \frac{\partial_{n4}}{\partial_y} \\ \frac{\partial_{n1}}{\partial_y} \; \frac{\partial_{n1}}{\partial_x} \; \frac{\partial_{n2}}{\partial_y} \; \frac{\partial_{n2}}{\partial_x} \; \frac{\partial_{n3}}{\partial_y} \; \frac{\partial_{n3}}{\partial_x} \; \frac{\partial_{n4}}{\partial_y} \; \frac{\partial_{n4}}{\partial_x} \end{bmatrix} \underline{\delta} \text{ -----------------6}$$

Ni=shape function for the node i

N1= (1- ζ) (1- η), N2=ζ(1- η), N3= ζ η and N4=η (1- ζ)

$$\underline{\varepsilon} = \lfloor \varepsilon_x \varepsilon_y \varepsilon_{xy} \rfloor \text{---7}$$

$$\underline{\delta} = [u1v1u2v2u3v3u4v4] \text{---8}$$

Equation (6) can be expressed as:

$$\underline{\varepsilon} = \underline{B}.\underline{\delta} \text{ ---9}$$

$$\sigma = \underline{D}\,\varepsilon = DB\delta \text{ ---10}$$

$$D = \frac{E}{(1+\nu)(1-\nu)} \begin{bmatrix} 1-\nu\nu 0 \\ \nu 1-\nu 0 \\ 00\frac{1-2\nu}{2} \end{bmatrix} \text{ ---11}$$

Strain energy U = $\frac{1}{2}\iiint \underline{\varepsilon}^{t}\, \underline{\sigma}\, dxdydz$ ---12

Hence U = $\frac{1}{2}\iiint (\underline{B}\delta)^{t}\, DB\delta dxdydz$

By substitution of equation (2) and (10) into (12)

$$U = \frac{1}{2\iiint \overset{t}{\delta}} BDB\delta dxdydz \text{ ---13}$$

Also, the work done by external forces ,W= $\overset{t}{\delta} F$ -----------------------------14

The total potential energy for the element $\chi = U - W$ ---------------------15

$$\chi = \underline{\overset{t}{\delta}} \frac{1}{2} \iiint \underline{\overset{t}{B}} DB\delta dxdydz - \overset{t}{\delta} F \text{ ---16}$$

Applying the minimum energy theorem, $\frac{\partial_x}{\partial \underline{\delta}} = 0$

Equation (16) becomes:

$$\iiint \underline{\overset{t}{B}} D\, \underline{B}\, \underline{\delta}\, dxdydz - F = 0 \text{ ---17}$$

$\underline{Ke}\delta = F$ --18

Where $\underline{K}e = \iiint \underline{B}^{t} D \underline{B}\, dxdydz$

For plane strain; dz= constant =t (element thickness)

Thus $\underline{K}e = \iint tB^{t} DBdxdy$ ---19

In large stain solids the Cauchy stress σ in equation 10 is decomposed into deviatory part plus pressure part:

$\underline{\sigma} = \underline{\sigma}^{-} - [q]p$ ---20

$\underline{\sigma}^{-}$ =Cauchy stress deviator

$[q]$= [1 11 0 0 0]

$P = \left(\dfrac{\sigma_x + \sigma_y + \sigma_z}{3} \right)$. The pressure is independently interpolated.

Simulation and results:

The closure and pressing force plot, versus displacement are used to investigate the effect of different strain rates on closure of voids located at specified positions singly at a time and collectively.

In forging process, the important step is the step where the void is healed completely such that avert the possibility of reopening of void during manipulation process. Accordingly, the simulation where made up to the instant of closure of voids. The model built as a circle containing a central void as shown in fig. (1), the simulation procedures taken according to the following conditions:-

1-Taken the void as central void of the cylindrical ingot with 0.1 ratio of the inner to outer radius and different strain rates of closure as follows:-

A- Strain rate of 0.11/min, the results are shown in figs. (2,3,4)

B- Strain rate of 0.25/min, the results are shown in figs. (5,6)

C- Strain rate of 0.3/min, the results are shown in figs. (7,8)

D- Strain rate of 0.68/min, the results are shown in figs. (9,10)

2- Taken the void as a central void of the cylindrical ingot with 0.15 ratio and the different strain rates of closure representative as follows:

A- Strain rate of 0.11/min, the results are shown in figs. (11, 12, 13)

B- Strain rate of 0.25/min, the results are shown in figs. (14, 15)

C- Strain rate of 0.3/min, the results are shown in figs. (16, 17)

D- Strain rate of 0.68/min, the results are shown in figs. (18, 19)

3-Taken the void as a central void of the cylindrical ingot with of 0.2 ratio with the different strain rates of closure as follows:

A- Strain rate of 0.11/min, the results are shown in figs. (20, 21, 22)

B- Strain rate of 0.25/min, the results are shown in figs. (23, 24)
C- Strain rate of 0.3/min, the results are shown in figs. (25, 26)
D- Strain rate of 0.68/min, the results are shown in figs. (27, 28)

4- Figs. (A to D) represent the relations of the strain rate with displacement (void closure), max. Stress (Von Misses), equivalent stress (σ_e) and total strain (Von Misses) for different ratios.

Discussions and conclusions:

The results can get from the above figures summarized as follows:

1- From the force – displacement curves, it can be observed that the force (forming force) for void closure decrease with increase the ratio with the same closure strain rate, this shown in figs. (2, 11, 20).

2- For the deformation in (y) direction (uy) for all ratios are shown in figs. (3,5,7,9,12,14,16,18,21,23,25,27). It can be observed that highest deformation concentrated at the bottom of the ingot with highest strain rate at all ratios stages which cause best void closure (Figs. 9,18, 27).

3- When compare the result shown in figs.(4,6,8,10,13,15,17,19,22,24,26,28) for total strain in (y) direction it can observed with same conditions that the highest (ε_y) happened on the highest strain rate at highest third ratio which also cause highest void closure (Figs. 10,19,28). From the points mentioned above it can be conclusion that the voids healed by the best result when used high strain rate with highest ratio of central void radius to outer radius of cylindrical ingot and the highest stress concentration happens at the lowest ratio.

4- Figs.(A to D) represent the relations for the strain rate with the displacement, stress (y direction), equivalent stress (σ_e) (Von Misses) and total strain (ε_y) (Von Misses) for different ratios.

The relations for strain rate with displacement (y) shows that the displacement for all ratios are the same for the last value of the strain rate which cause the healing of the void (Fig. A). Fig.B shows the relation of the strain rate with stress in y-direction from which it can be seen that the highest ratio takes lowest stress value than the others for last strain rate value (void closure). The same results can be shown in Fig. C that the highest ratio represents the lowest value of equivalent stress (σ_e) for void closure and also for Fig. D for the total strain (ε_y)

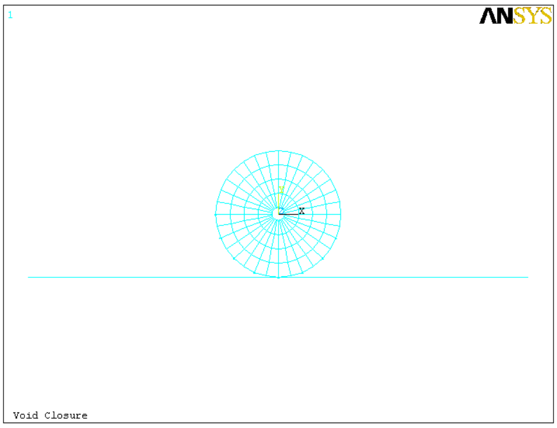


Fig.1

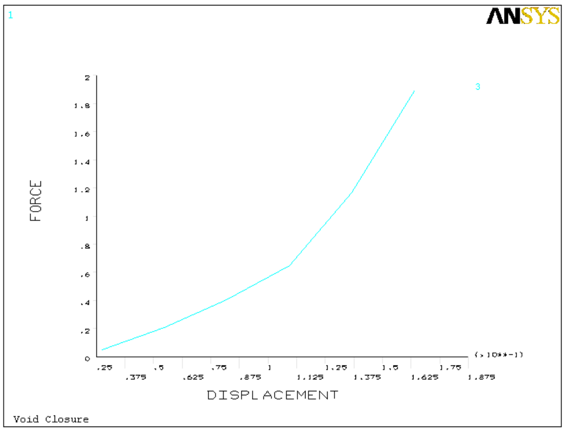


Fig.2

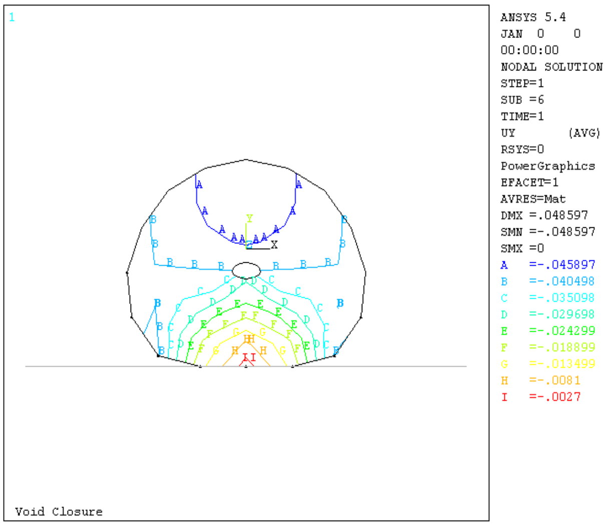


Fig.3

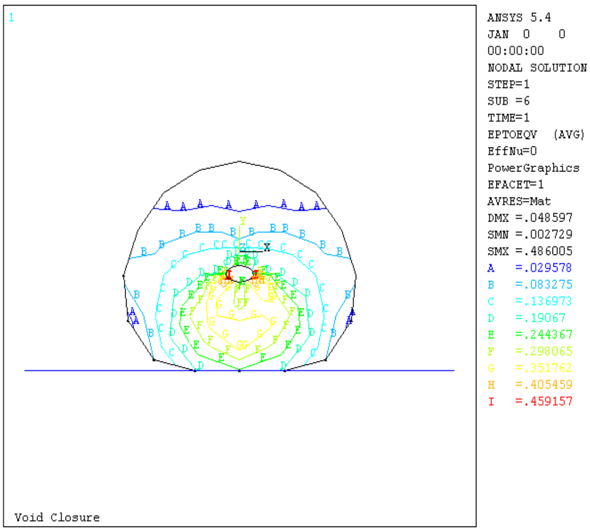


Fig.4

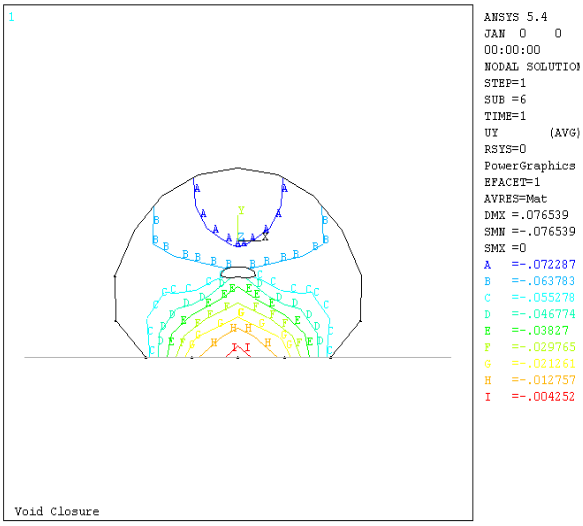


Fig.5

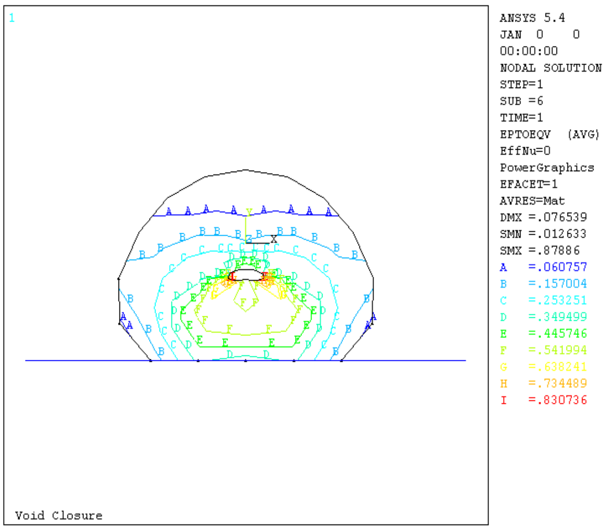


Fig.6

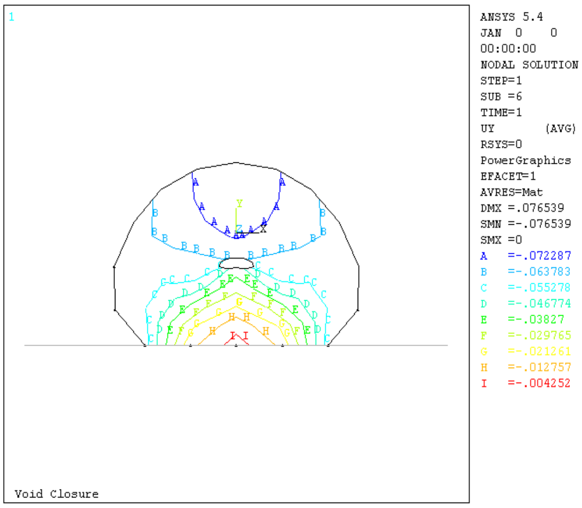


Fig.7

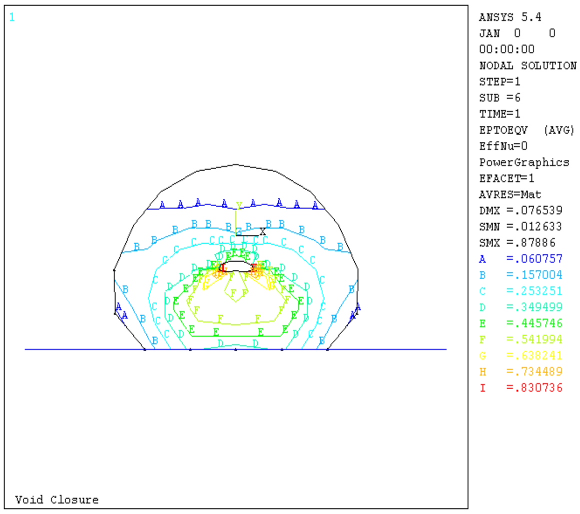


Fig.8

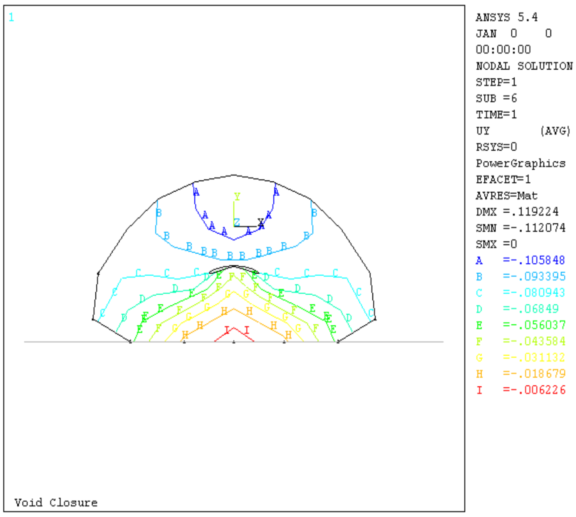


Fig.9

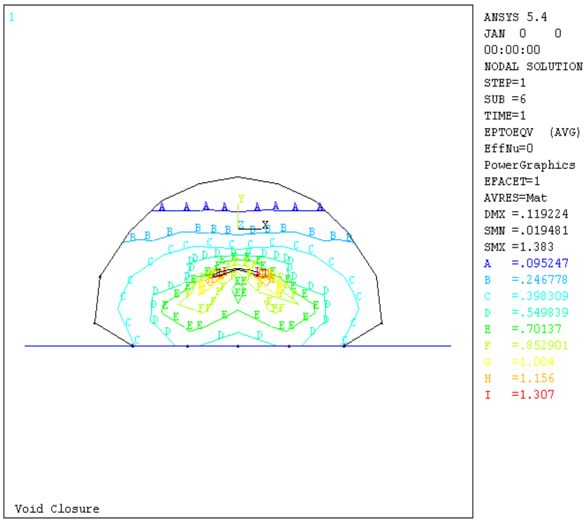


Fig.10

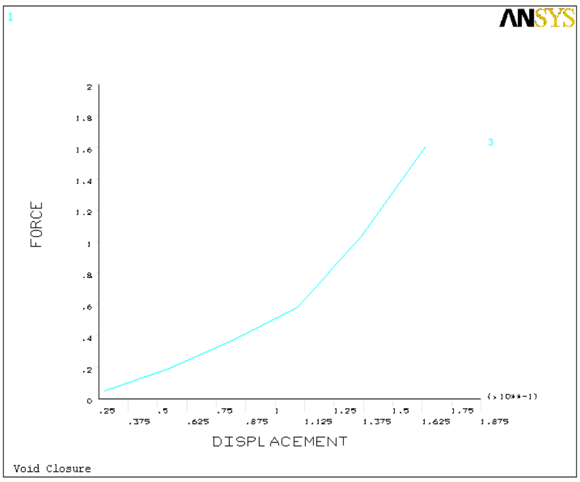


Fig.11

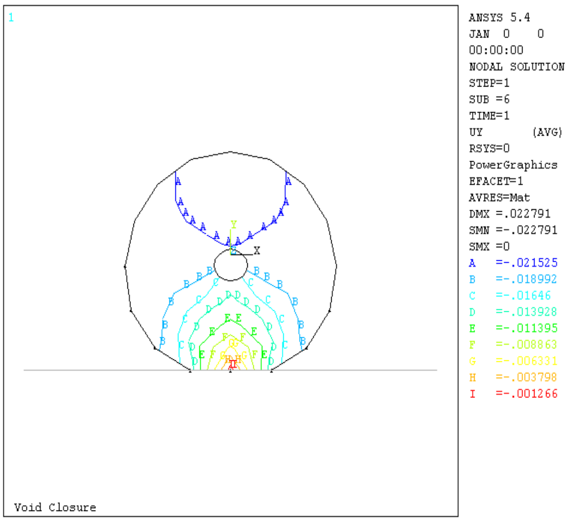


Fig.12

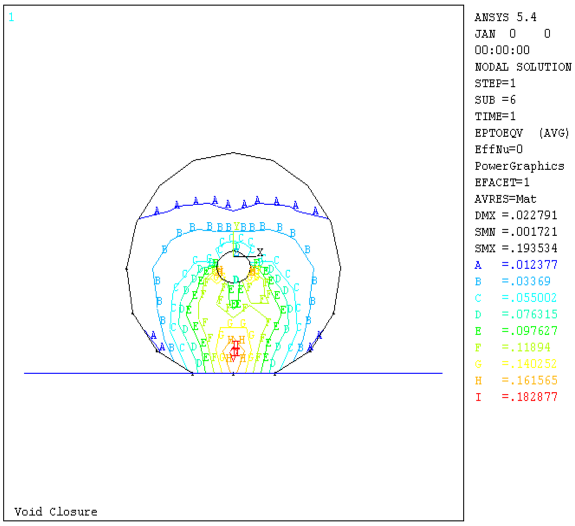


Fig.13

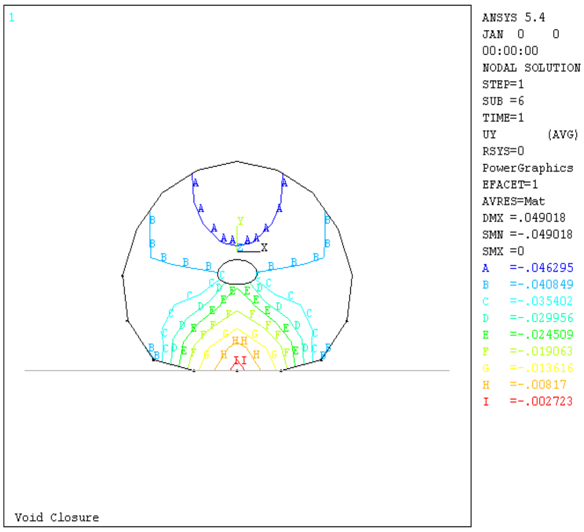


Fig.14

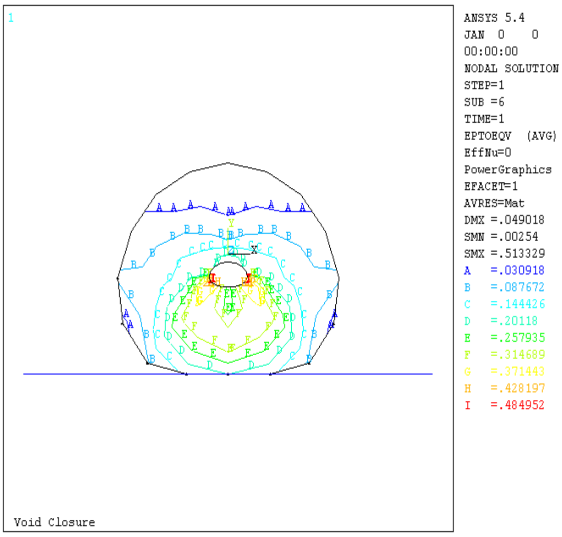


Fig.15

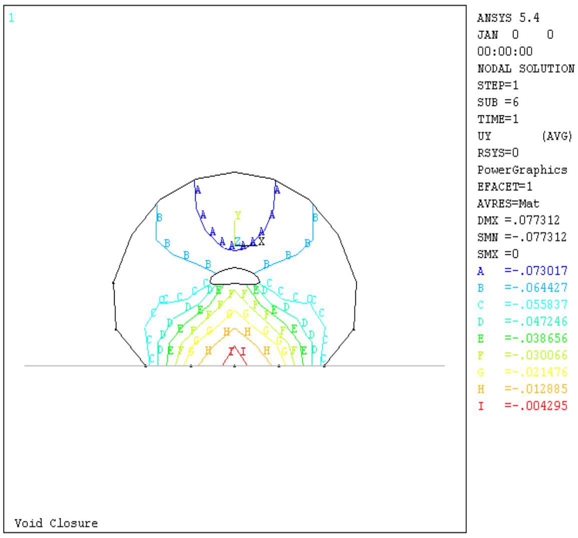


Fig.16

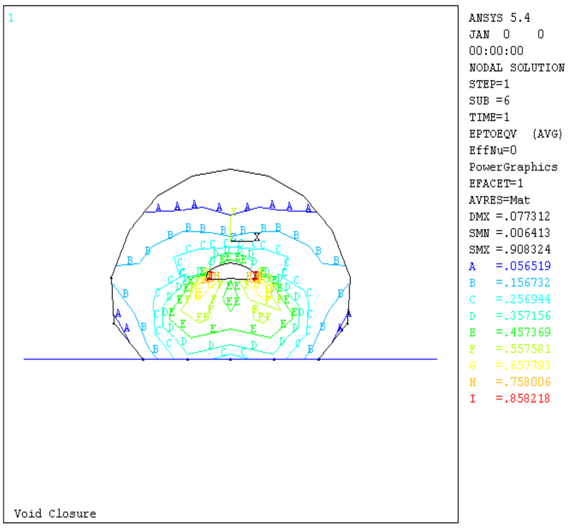
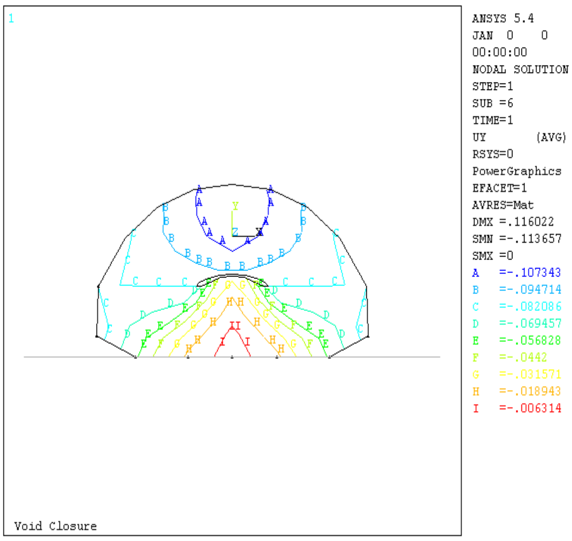


Fig.17



Fg.18

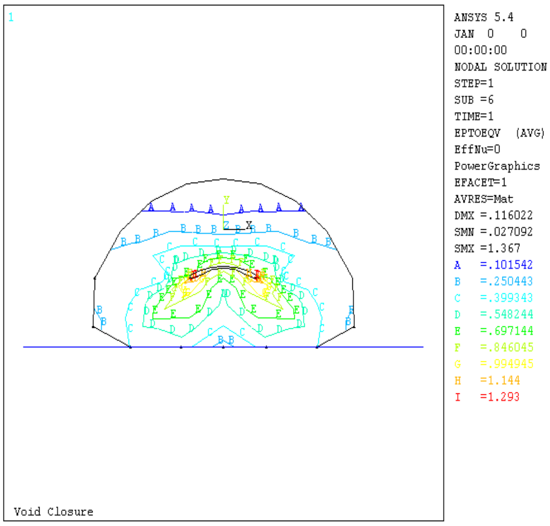


Fig.19

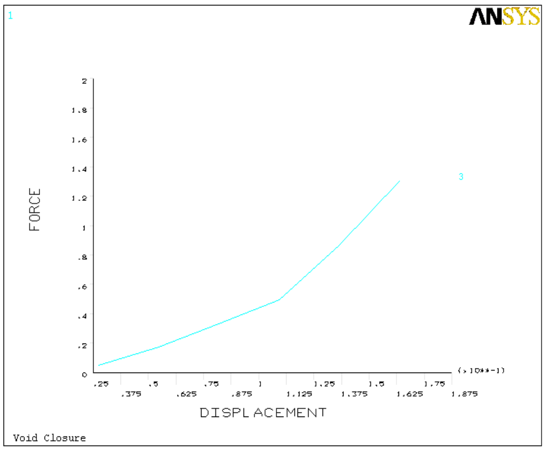


Fig.20

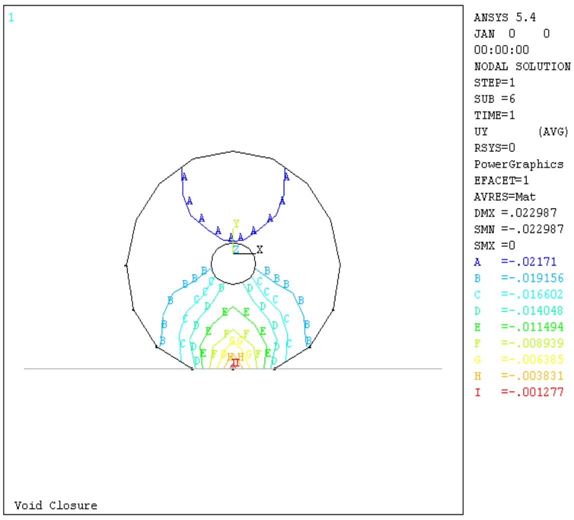


Fig.21

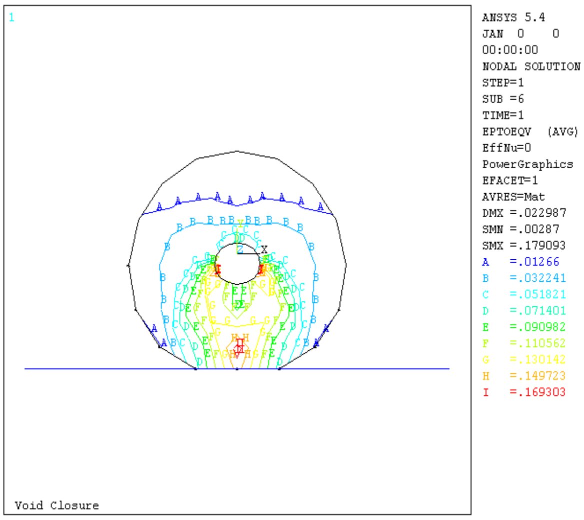
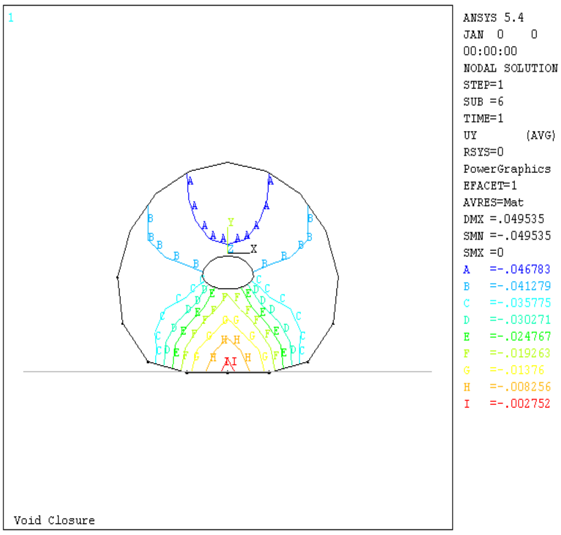


Fig.22



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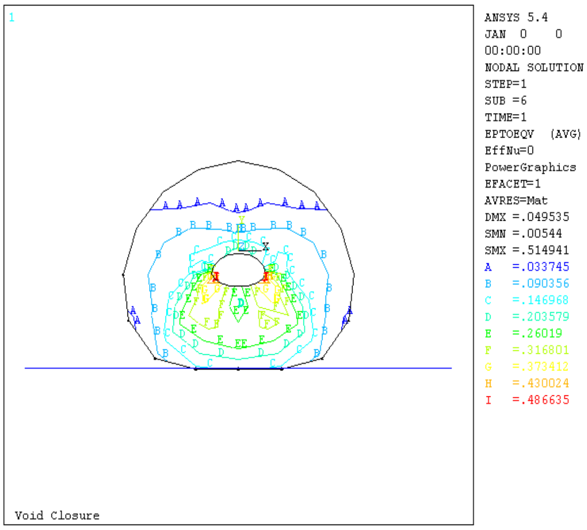


Fig.24

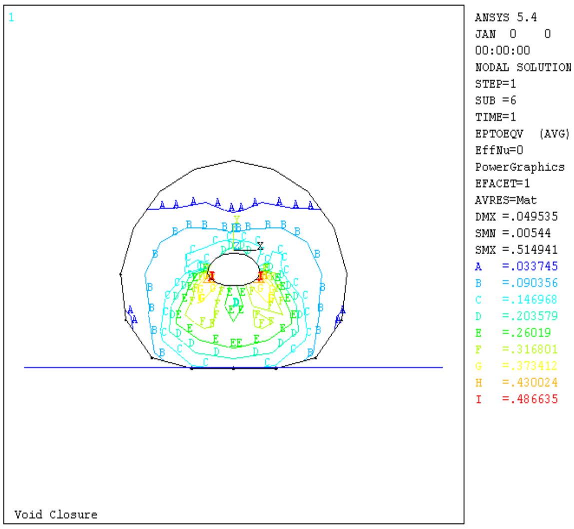


Fig.25

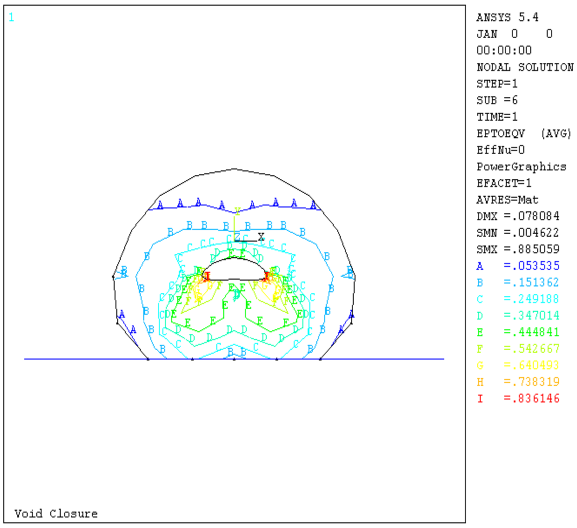


Fig.26

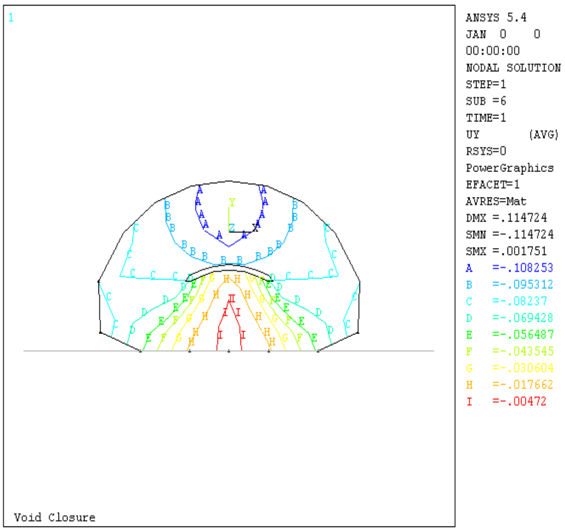


Fig.27

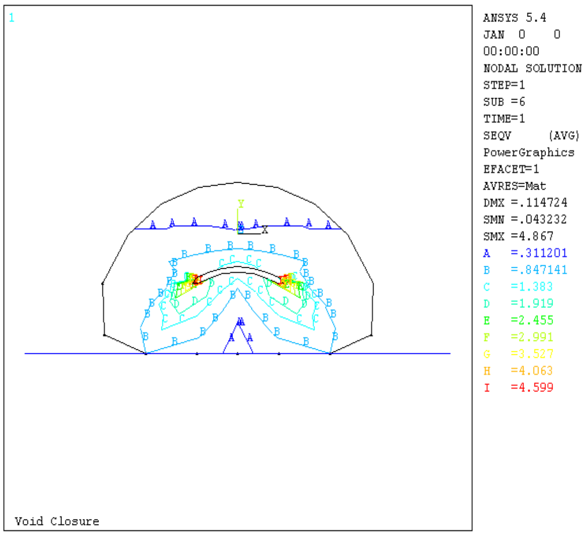
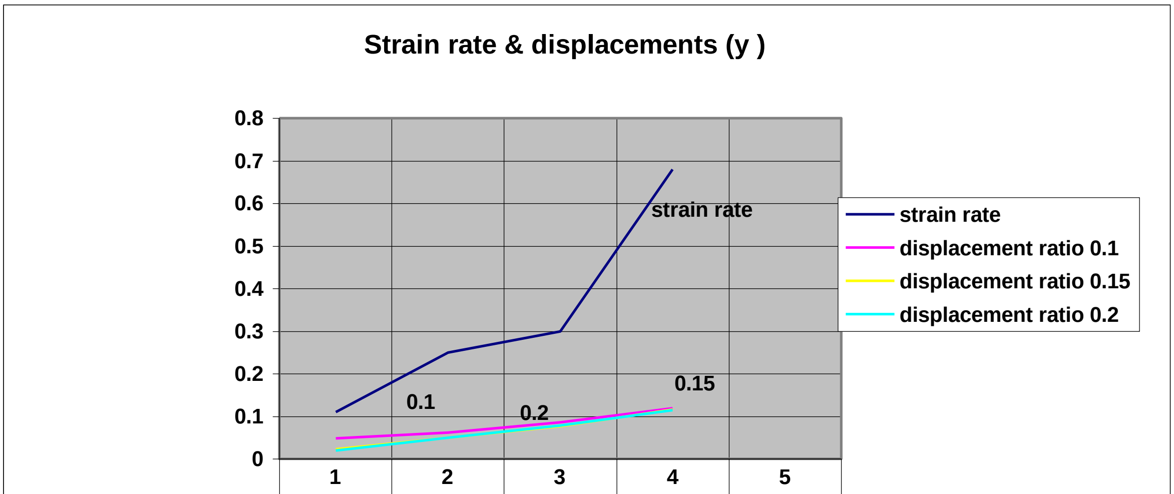
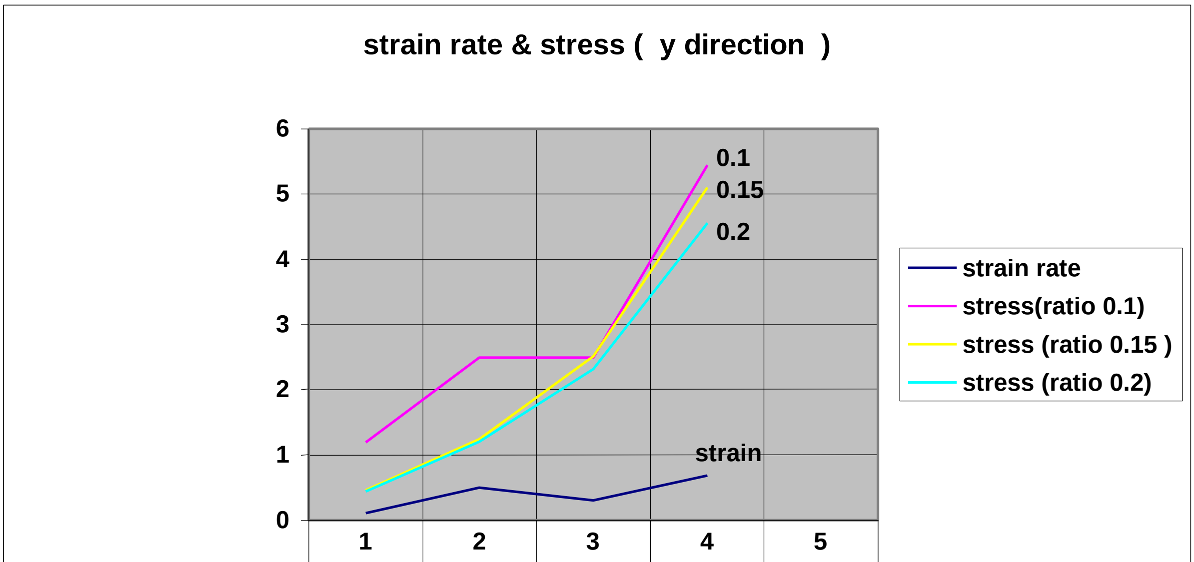


Fig.28



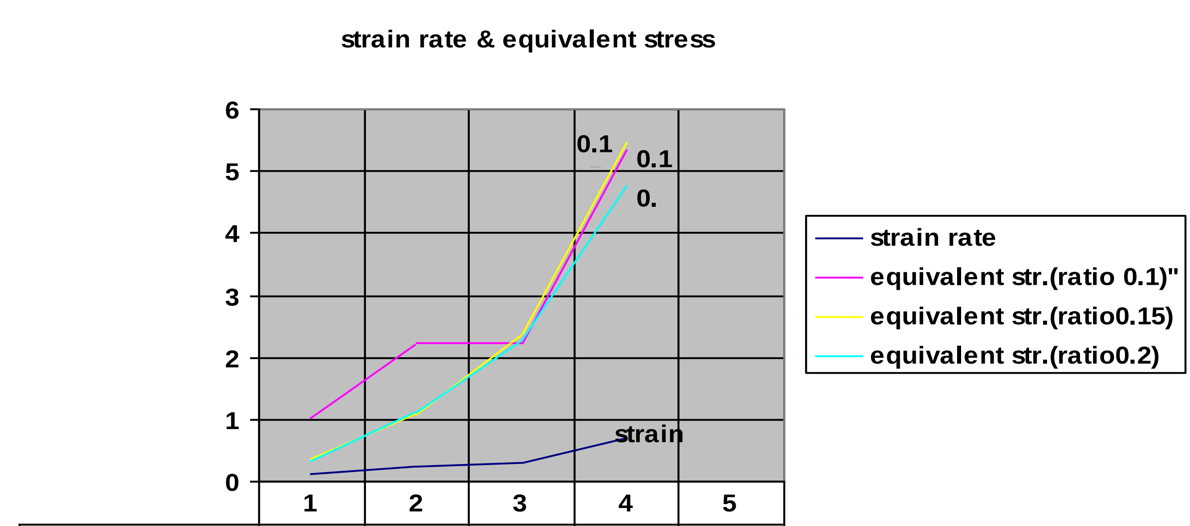
	1	2	3	4	5
strain rate	0.11	0.25	0.3	0.68	
displacement ratio 0.1	0.048	0.061	0.086	0.119	
displacement ratio 0.15	0.022	0.049	0.077	0.116	
displacement ratio 0.2	0.02	0.049	0.078	0.114	

Fig. A



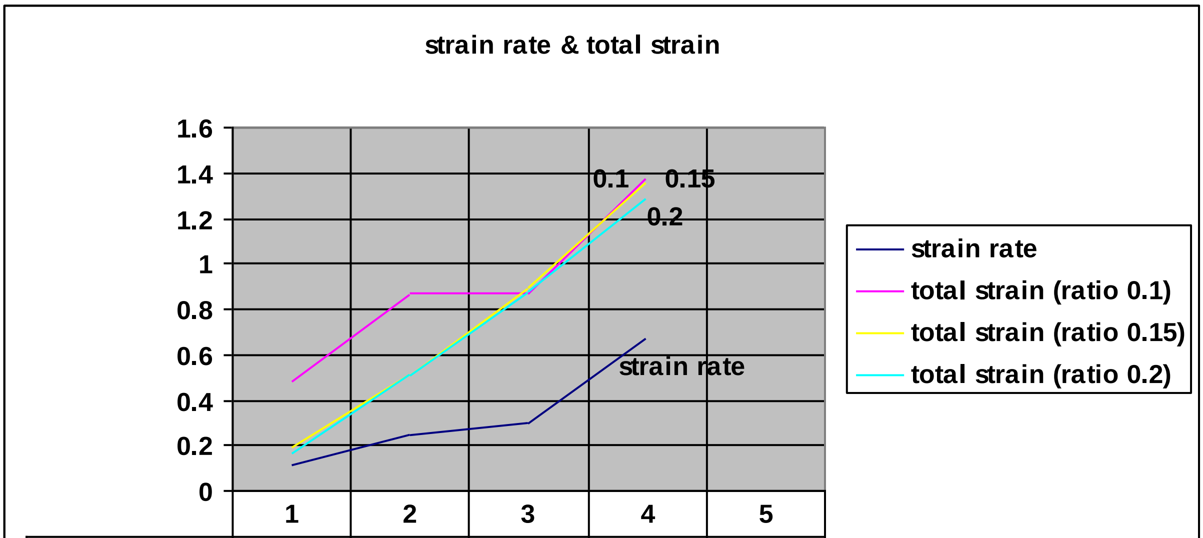
	1	2	3	4	5
strain rate	0.11	0.5	0.3	0.68	
stress(ratio 0.1)	1.19	2.49	2.49	5.447	
stress (ratio 0.15)	0.46	1.237	2.514	5.099	
stress (ratio 0.2)	0.44	1.2	2.316	4.55	

Fig.B



	1	2	3	4	5
strain rate	0.11	0.25	0.3	0.68	
equivalent str.(ratio 0.1)"	1.027	2.23	2.23	5.359	
equivalent str.(ratio0.15)	0.36	1.1	2.38	5.49	
equivalent str.(ratio0.2)	0.34	1.11	2.3	4.8	

Fig.C



	1	2	3	4	5
strain rate	0.11	0.25	0.3	0.68	
total strain (ratio 0.1)	0.48	0.87	0.87	1.38	
total strain (ratio 0.15)	0.19	0.51	0.9	1.36	
total strain (ratio 0.2)	0.17	0.51	0.88	1.29	

Fig.D

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