1.0. Summary

The analysis of the retaining ring is modeled using Abaqus software to obtain the force required to open the ring. The study involved different type of element types such as CPS4R and CPS4, finite element method. A parametric mesh density study was performed with nine different element breakups in order to obtain converged solution. Results showed the higher element meshes generated better approximations to the actual solution. The coarser meshes were too stiff and underestimated the actual deflected shape. Different kinds of materials were used such as carbon steel, stainless steel, and copper in order to acquire which material has cost and allowable stress. Finally, a new design was made to obtain lower stresses, allows us to select more materials.

1.1. Introduction

A retaining ring is a fastener that holds components or assemblies onto a shaft or in a housing/bore when installed in a groove. Once installed, the exposed portion acts as a shoulder which retains the specific component or assembly. Circlips are a type of retaining ring. Self-locking retaining rings may be installed in applications where there is no groove. Retaining rings are typically made from carbon steel, stainless steel or beryllium copper and may feature a variety of finishes for corrosion protection depending on the type of environment in which they are used. There are three main types of retaining rings available, each of which may then be broken down into sub-types depending on unique application needs [1]:

1. **Tapered section**
    - Axially assembled
        - Inverted
        - Beveled
        - Bowed
    - Radially assembled
    - Self-locking
2. **Constant section**
3. **Spiral**

1.2. Finite Element Method

The One of the most widely used techniques today is the *Finite Element Method* (FEM). FEM is a numerical approach commonly used to solve engineering mechanics problems. Many general finite element code packages have been written over the years with user friendly windows and menus (GUI) which allow for easy geometry setup, boundary condition manipulation and evaluation/post-processing of common structural problems. Some of the most popular commercial codes in the industry are Abaqus, ANSYS, MSC Nastran, and MARC. Abaqus will be the code used for the work in this research.

The FEM subdivides the model, in this case a retaining ring, into smaller sections (elements) and determines values at each end (nodes) of these smaller retaining ring. A physical, finite element mesh is converted into a mathematical model. The differential equations involved in the model are minimized and solved through algebraic matrix manipulation of a linear system of equations. One advantage this method has over some of the others to be studied is the way the boundary conditions are handled. The boundary conditions are treated as integrals in a functional, which is to be minimized. By doing this, the model construction is independent of the actual boundary conditions. This allows the user to easily modify the loading, constraints, and actual geometric shape. It is very beneficial when there are partial differential equations, derivatives, and irregular shapes involved [2].

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1.3. Problem Description

The parameters of the retaining ring to be analyzed are shown in figure 1.

1.3.1 Material Properties

The properties of the fluid are assumed to be constant, as shown in Table 1.

Table 1: Material Properties and its cost [3].

Material/Condition	Modulus of Elasticity psi	Poisson's Ratio	Cost ($US/kg)	Relative Cost	Yield Strength psi
Stainless alloy 304	29×10^6	0.3	6.20-9.20	6.0	40,000
Stainless alloy 316	29×10^6	0.3	6.20-11.70	7.3	40,000
Stainless alloy 405	29×10^6	0.3	9.20	7.1	40,000
Stainless alloy 440-tempered at 315C	29×10^6	0.3	9.20	7.1	240000
Aluminum Alloy 1100	10×10^6	0.33	5.3-5.50	4.2	15228.9585
Aluminum Alloy 2024	10.5×10^6	0.33	12.50-19.50	12.9	14,000
Copper C17200 Heated-treated and aged	18.6×10^6	0.3	9.0-36.00	17.5	140-175E3
Magnesium Alloy AZ31B	6.5×10^6	0.35	3.0-3.3	2.4	32000
Chemical Lead	2×10^6	0.41			1200
Lead-tin solder (60Sn-40Pb)	4.4×10^6	0.33			1600
Cast iron- Ductile irons Grade 120-90-02	23.8×10^6	0.28	2.00-3.20	2.0	90000

1.3.2 Problem Set Up

Figure (1) shows the dimensions of the retaining ring.

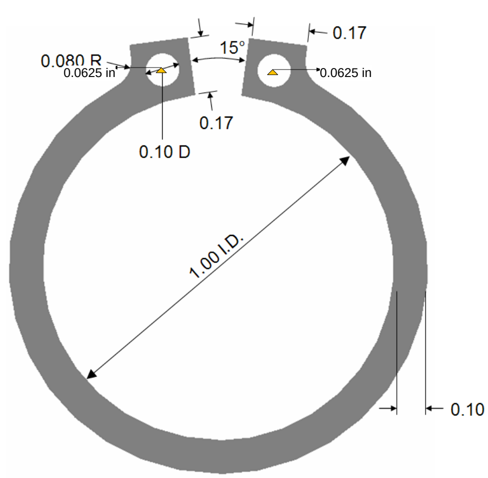


Figure 1: Problem Description.

1.3.3 Boundary Conditions

Displacements on both rings were applied with an amount of 0.0625 in in each ring.

1.4. Coarse Grid

A 9328 quadrilateral mesh was used in this validation study, and is shown in Figure 2.

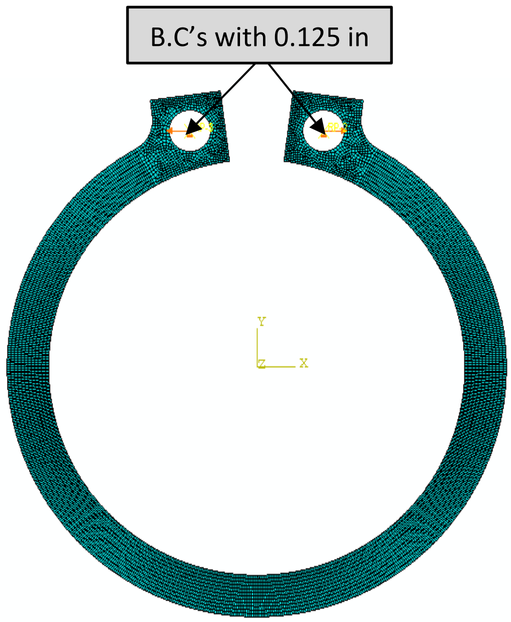


Figure 2: quadrilateral mesh.

1.5. Case Setup

The Abaqus case was set up using different materials section 1.3.1 and boundary conditions described in Section 1.3.2. Two runs were made, by getting the converged solution and then changing different materials for the converged grid to obtain safety factor greater than 1, by redesigning the model to decree the Von Mises stress.

Table 2: Case set up.

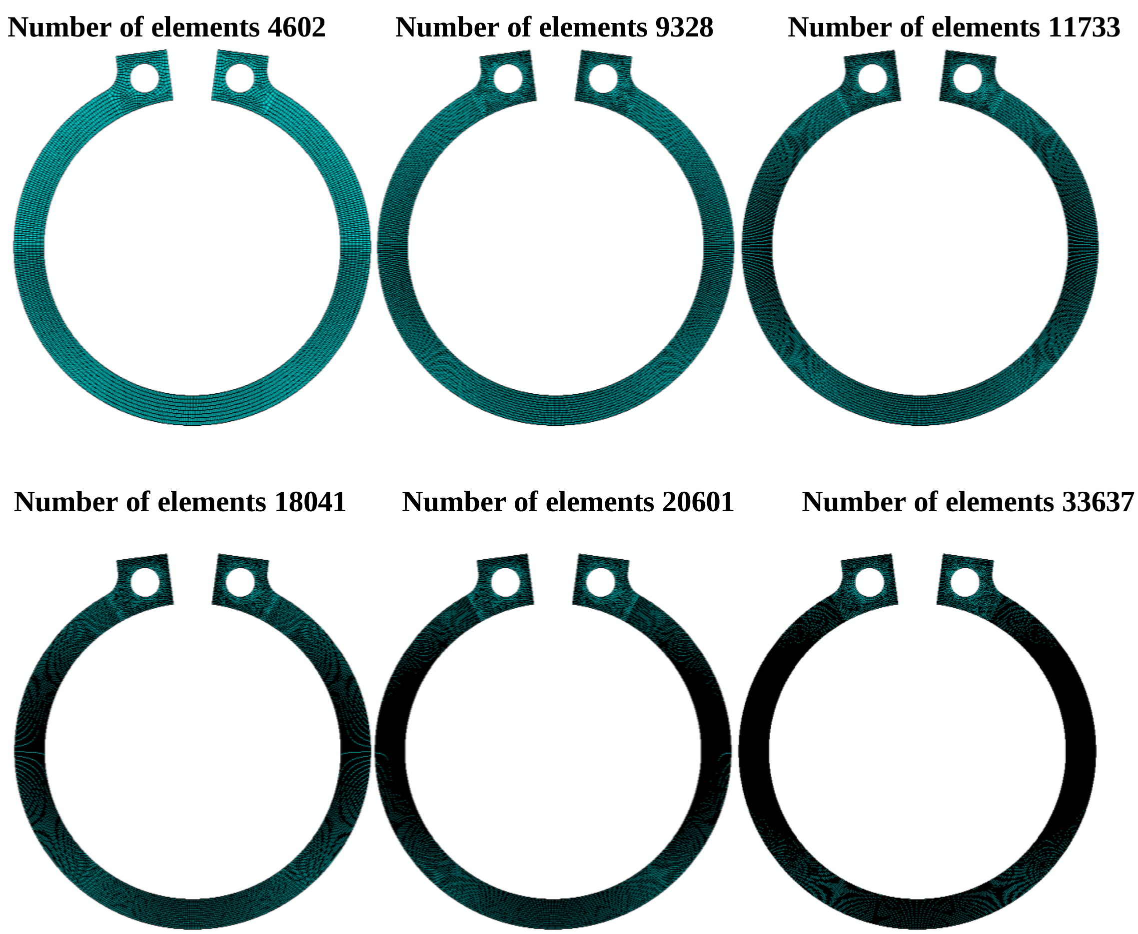
Given Model	New Model
Obtain converged solution and change different materials	Decreasing S,Mises stress

1.6. Calculations

In our calculations, Abaqus was run for two different types of element, CPS4I (Incompatible modes) and CPS4R (Reduced integration). While CPS4I has given converged solution since it uses four points in its calculations, CPS4R never gives converged solution since it uses only one point it its calculations. Table (3) and (4) provide results for both CPS4I CPS4R respectively.

1.7. Grid Convergence Study

Eight different resolutions figure (3) were made for the same family of grid. Based on the selected grids, Abaqus was run on each grid to obtain the value in which we decided to make our study. In our case, the stress S, S_{11} was measured for each grid resolution table 3.



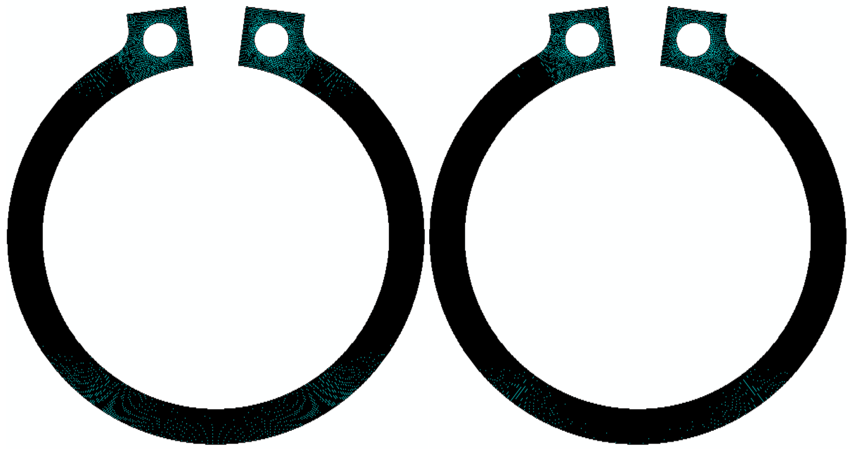


Figure 3: shows coarse, medium, and fine mesh for the same family of grid.

Table 3: gives the results for grid convergence for different number of nodes using Stainless.

CPS4I	**Approximate global size**	**Number of elements**	S, S_{11} psi	U, U_1 in
Coarse Mesh	0.01	4602	132799.4375	0.06957968
Medium Mesh	0.01	9328	132985.59375	0.069579586
Fine Mesh	0.01	11733	132984.984375	0.06957965
Very fine mesh 1	0.01	18036	133067.328125	0.06957964
Very fine mesh 2	0.01	20596	133067.203125	0.06957963
Very fine mesh 3	0.01	33645	133141.5625	0.06957960
Very fine mesh 4	0.01	40438	133153.03125	0.06957960
Very fine mesh 5	0.01	51138	133169.53125	0.06957960

Table 4: gives the results for grid convergence for different number of nodes using CPS4R.

CPS4R	**Approximate global size**	**Number of elements**	S, S_1 psi	U, U_1 in
Coarse Mesh 1	0.01	1391	97085.875000	0.069580
Coarse Mesh	0.01	4602	114888.26562	0.069579631
Medium Mesh	0.01	9328	120947.8671875	0.069579586
Fine Mesh	0.01	11733	120947.99218750	0.069579601
Very fine mesh 1	0.01	18036	124002.5937	0.069579631
Very fine mesh 2	0.01	20596	124002.671875	0.069791377
Very fine mesh 3	0.01	33645	127073.71875	0.069579616
Very fine mesh 4	0.01	40438	127548.203125	0.069579631
Very fine mesh 5	0.01	51138	128307.1796875	0.069791384

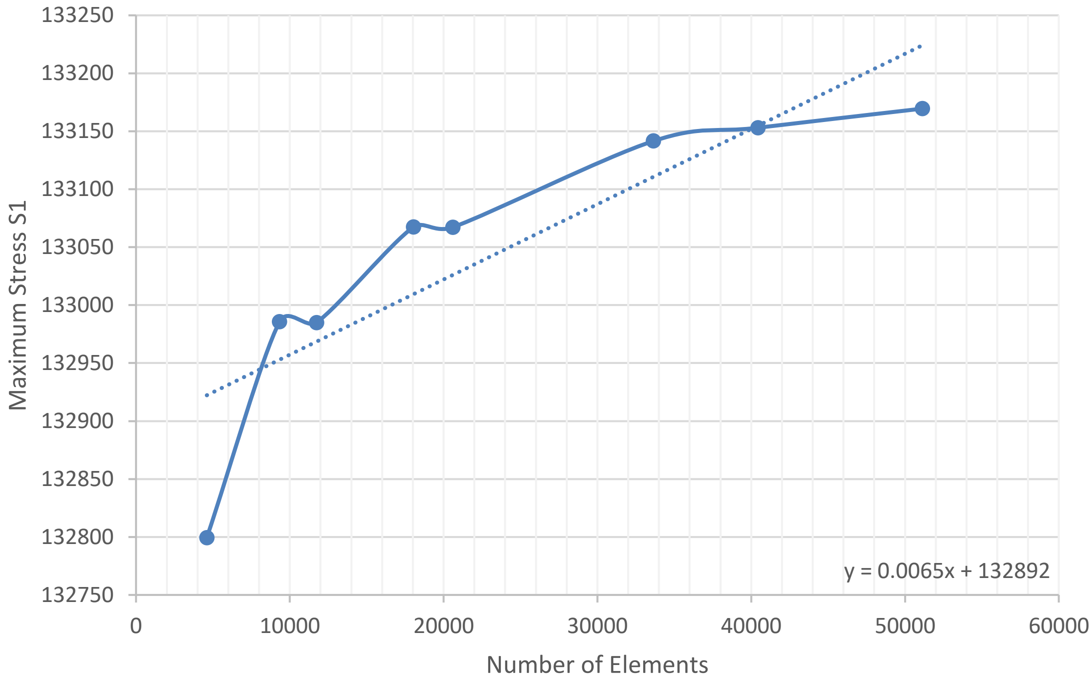


Figure 4: Grid Convergence for the retaining ring.

1.8. Results

1.8.1 Choosing different material

It is important to measure the safety factor for each selected material Equation (1) since it provides the ratio between the yield strength for the given material and Von Mises stress that is obtained by solving the problem. Table (1) provides the data for each material and its price and yield strength. Since the converged solution was obtained, now our aim is to measure the safety for each chosen material. Table (5) gives the results for each selected material. As we can see, the three highlighted materials provide a safety factor greater than one, which means that our design using these material is valid.

$$\boxed{n = \frac{S_y}{\sigma_{vm}} = \frac{Yield\ Strngth}{S, Mises}} \qquad (1)$$

Table 5: shows how the safety factor change with different material.

CPS4I	$S, Mises\ psi$	$n = \frac{S_y}{\sigma_{vm}}$
Stainless alloy 304	133177.703125	$n = \frac{40,000}{133177.703125} \cong 0.3$
Aluminum Alloy 1100	45919.9375	$n = \frac{15228.9585}{45919.9375} \cong 0.33$
Magnesium Alloy	29850.173828	$n = \frac{32000}{29850.173828} \cong 1.07202$
Chemical Lead	9186.711914	$n = \frac{1200}{9186.711914} \cong 0.13$
Lead-tin solder (60Sn-40Pb)	20204.773438	$n = \frac{1600}{20204.773438} \cong 0.078$
Copper C17200	85401.578125	$n = \frac{175000}{85401.578125} \cong 2.049$
Stainless alloy 440-tempered at 315C	133153.015625	$n = \frac{240000}{133153.015625} \cong 1.8024$

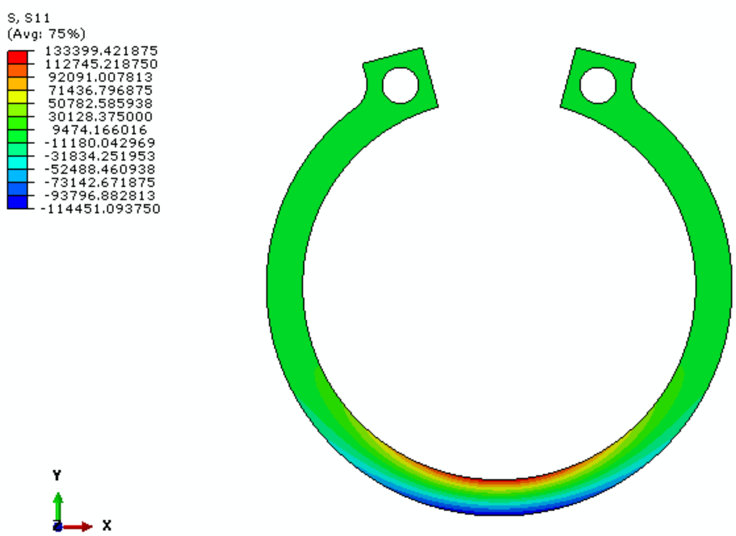


Figure 5: shows stress distributions for number of elements of 40438 for Stainless alloy 304.

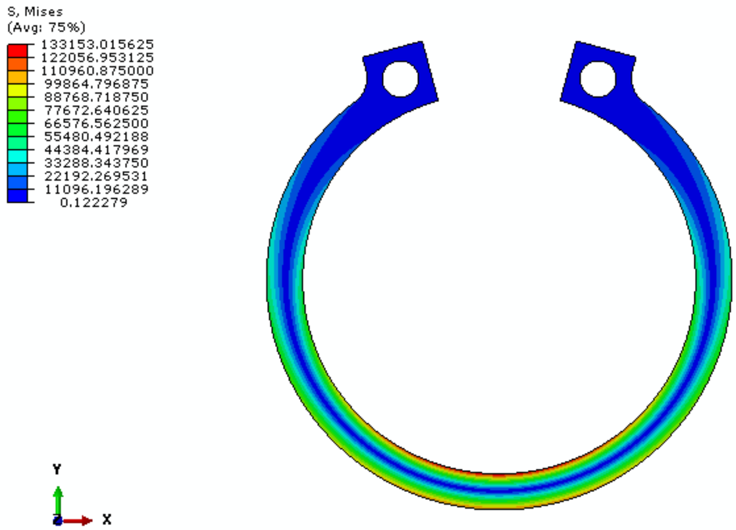


Figure 6: shows Von Mises stress distributions for number of elements of 40438 for Stainless alloy 304.

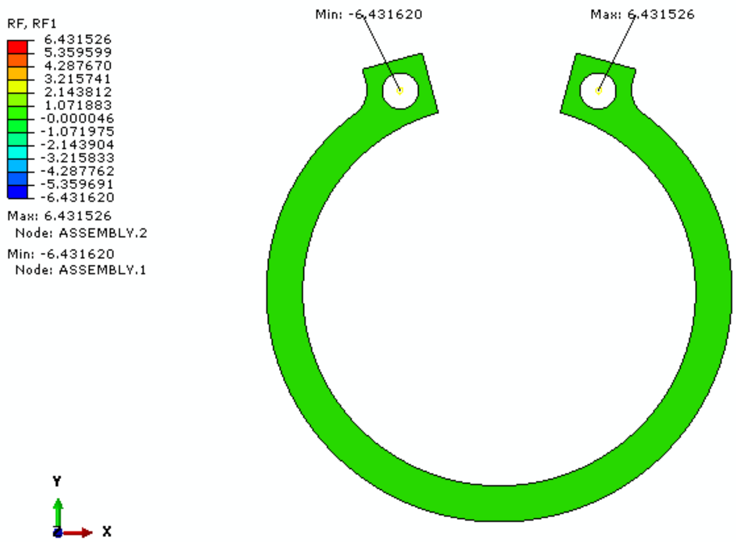


Figure 7: shows reaction force distributions for number of elements of 40438 for Stainless alloy 304.

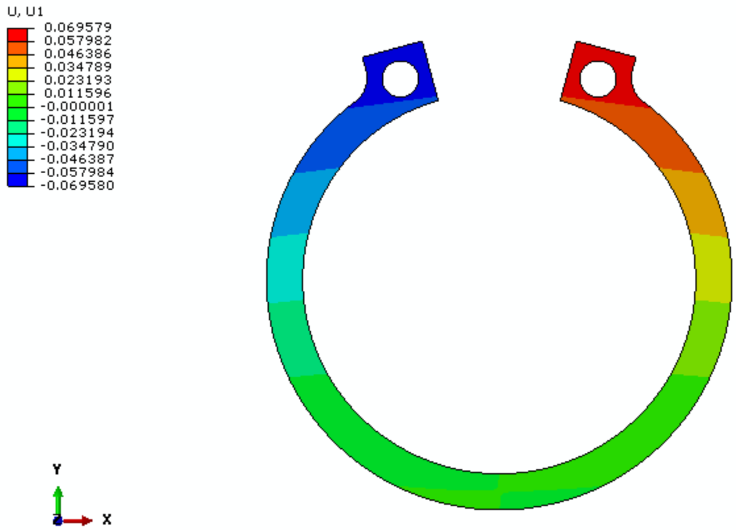


Figure 7: shows displacement distributions for number of elements of 40438 for Stainless alloy 304.

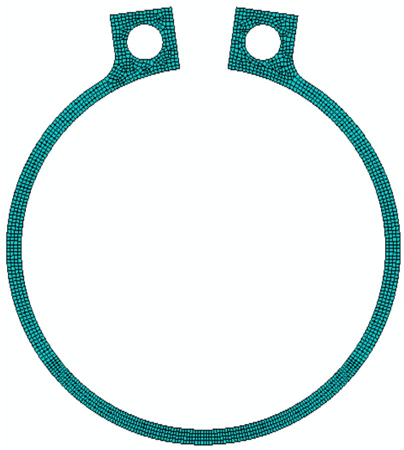
1.8.2 Redesigning the model to reduce stresses

It is noticeable from the given design that the stress is too high as well as the required force to open the ring. Hence, our aim is to minimize the stress so that we can choose more material with safety factor higher than on. To do so, we have to decrease the thickness to a reasonable number. In this design, the thickness of the retaining ring decreased to 0.04 instead of 0.1. Table (6) shows the grid convergence study for the new design. Table (8) shows the gird convergence study for thickness of 0.02 of the retaining ring.

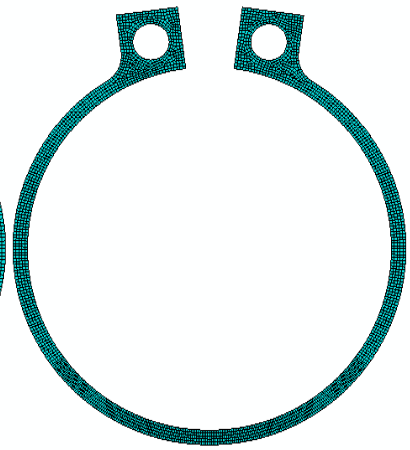
Table 6: gives the results for grid convergence for different number of nodes using Stainless.

CPS4I	**Approximate global size**	**Number of elements**	$S, S_{11}\ psi$
Coarse Mesh	0.01	1768	54496.523438
Medium Mesh	0.008	2893	54513.648438
Fine Mesh	0.006	5408	54519.812500
Very fine mesh 1	0.005	7651	54518.59375

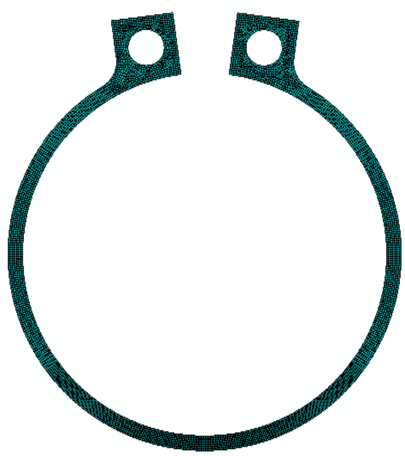
Number of elements 1768



Number of elements 2893



Number of elements 5408



Number of elements 7651

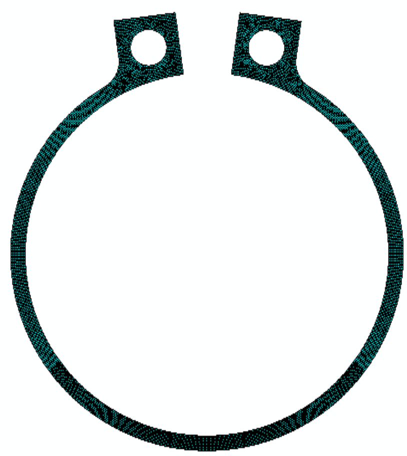


Figure 8: shows coarse, medium, and fine mesh for the same family of grid.

Table 7: shows how the safety factor change with different material for thickness of 0.04.

CPS4I	$S, Mises\ psi$	$n = \frac{S_y}{\sigma_{vm}}$
Stainless alloy 304	54395.976563	$n = \frac{40,000}{54395.976563} \cong 0.74$
Aluminum Alloy 1100	18759.667969	$n = \frac{15228.9585}{45919.9375} \cong 0.812$
Magnesium Alloy	12194.839844	$n = \frac{32000}{29850.173828} \cong 2.6241$
Chemical Lead	3753.232	$n = \frac{1200}{9186.711914} \cong 0.32$
Lead-tin solder (60Sn-40Pb)	8254.253906	$n = \frac{1600}{20204.773438} \cong 0.194$
Copper C17200	34888.460938	$n = \frac{175000}{85401.578125} \cong 5.016$
Stainless alloy 440-tempered at 315C	54395.976563	$n = \frac{240000}{133153.015625} \cong 4.4121$

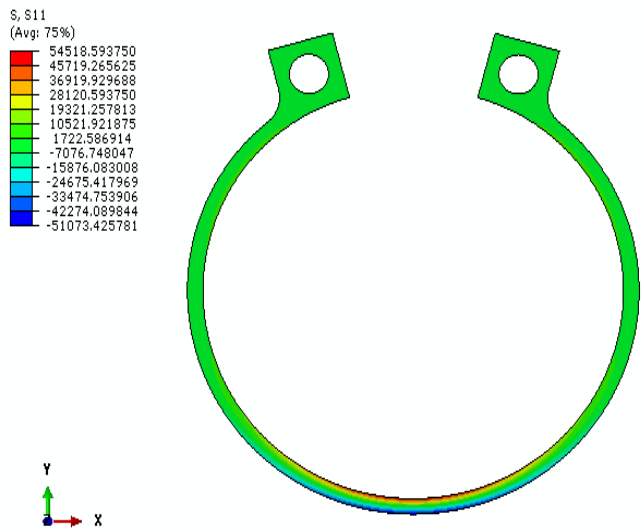


Figure 9: shows stress distributions for number of elements of 7651 for Stainless alloy 304.

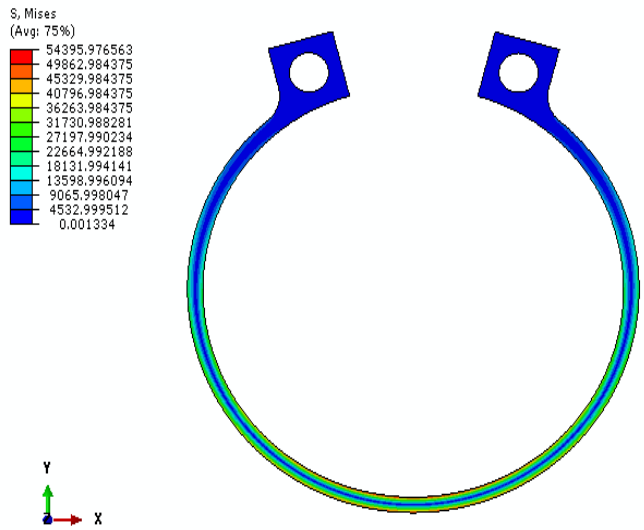


Figure 10: shows Von Mises stress distributions for number of elements of 7651 for Stainless alloy 304.

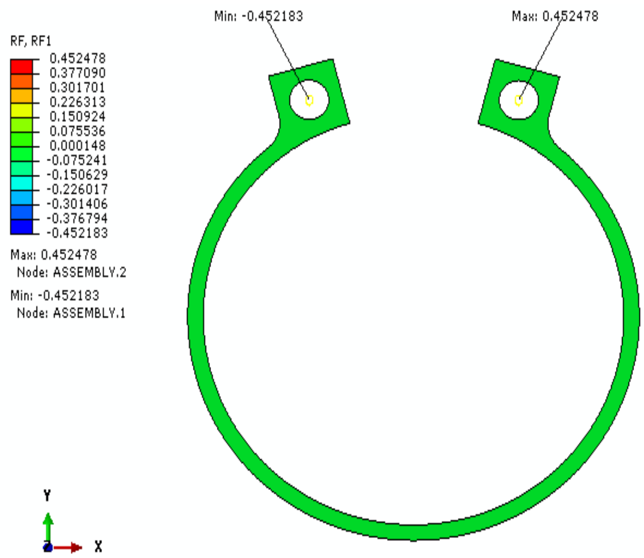


Figure 7: shows max. and min. reaction force distributions for number of elements of 7651 for Stainless alloy 304.

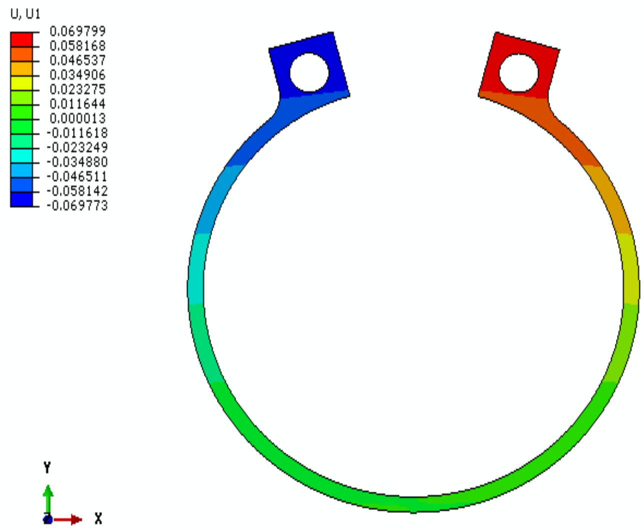


Figure 7: shows displacement distributions for number of elements of 7651 for Stainless alloy 304.

Table 8: gives the results for grid convergence for different number of nodes using Stainless for thickness of 0.02.

CPS4I	**Approximate global size**	**Number of elements**	$S, Mises\ psi$
Coarse Mesh	0.01	1204	27264.984375
Medium Mesh	0.008	2125	27330.816406
Fine Mesh	0.005	4770	27355.808594
Very fine mesh 1	0.004	7428	27386.8835938
Very fine mesh 2	0.003	13338	27382.792969

Table 9: shows how the safety factor change with different material-thickness 0.02.

CPS4I	$\boldsymbol{S, Mises\ psi}$	$\boldsymbol{n = \frac{S_y}{\sigma_{vm}}}$
Stainless alloy 304	27386.8835938	$n = \frac{40,000}{54395.976563} \cong 1.461$
Aluminum Alloy 1100	9434.085938	$n = \frac{15228.9585}{45919.9375} \cong 1.61425$
Magnesium Alloy	6132.608887	$n = \frac{32000}{29850.173828} \cong 5.22$
Chemical Lead	1887.376732	$n = \frac{1200}{9186.711914} \cong 0.636$
Lead-tin solder (60Sn-40Pb)	4150.997559	$n = \frac{1600}{20204.773438} \cong 0.38535$
Copper C17200	17545.449219	$n = \frac{175000}{85401.578125} \cong 9.9741$
Stainless alloy 440-tempered at 315C	27386.8835938	$n = \frac{240000}{133153.015625} \cong 8.7633$

1.9. Conclusion

Abaqus was used to obtain the material that gives safety factor higher than one. The design of retaining ring model was treated by getting a converged solution then change the material in order to obtain reasonable safety factor as well as redesigning it in order to decrease Von Mises stress since the original model gives high stresses, which limits us to choose only highly sophisticated materials. It is suggested either to use the given materials that have led to safety factor higher than one or by decreasing the thickness to 0.02, which might not be good practically.

1.10. References

1. http://www.rotorclip.com/about_retaining_rings.php
2. Avalone, E.A. and Baumeister, T, *Marks' Standard Handbook For Mechanical Engineers*, McGraw Hill, New York, New York, 1996
3. Callister, Jr., Rethwisch. "Materials Science and Engineering – An Introduction" (7th Ed.). John Wiley and Sons, 2009.