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Non Linear Simulation And Analysis Of A Neoprene Rubber Gasket

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Abstrak.
Makalah ini menyajikan simulasi dan analisis nonlinier gasket karet neoprene pada sambungan sambungan baut. Perangkat lunak FE ANSYS dengan kemampuan nonlinier digunakan untuk membuat model FE dan untuk mensimulasikan gasket karet neoprene hiperelastis. Penelitian ini bertujuan untuk mengetahui tegangan kontak dan deformasi gasket karet neoprene. Material gasket yang dipilih untuk analisis adalah karet neoprene yang memiliki sifat non-linier. Model simulasi berdasarkan sambungan bolted-flange dimana gasket berada ditengah-tengah rakitan bolted-flange. Ketika baut dikencangkan bersama-sama, ada tegangan kontak antara gasket dan flensa. Tegangan kontak maksimum antara paking dan flensa dievaluasi untuk memprediksi tekanan fluida internal maksimum yang dapat ditahan oleh paking neoprene, sedangkan deformasi maksimum digunakan untuk mengevaluasi geometri atau dimensi paking. Hasil penelitian menunjukkan tegangan kontak maksimum pada gasket sebesar 0,218 MPa pada torsi baut 20 N.m, sedangkan deformasi maksimum pada sumbu Y sebesar 7,1942 mm yang terjadi pada torsi baut 20 N.m. Deformasi maksimum gasket tidak mengganggu posisi baut sehingga kondisi ini dapat diterima untuk aplikasi nyata. Berdasarkan teori saat ini dan hasil simulasi, tekanan fluida internal maksimum yang dapat ditahan harus kurang dari 0,218 MPa jika tidak, fluida akan bocor melintasi paking.

Kata kunci: *paking polimer; stres termal; simulasi FE; ANSYS*

Abstract.
The paper presents nonlinear simulation and analysis of the neoprene rubber gasket in the bolted joint connection. FE software ANSYS with nonlinear capability is used to make FE model and to simulate the hyperelastic neoprene rubber gasket. The aims of the research are to find the contact stresses and the deformations of the neoprene rubber gasket. The gasket material chosen for the analysis is the neoprene rubber which has non-linear properties. The simulation model based on the bolted-flange connection where the gasket located in the middle of the bolted-flange assembly. When the bolts are thigtened together, the contact stresses exist betweeen the gasket and the flanges. The maximum contact stress between the gasket and flanges is evaluated to predict the maximum internal fluid pressure that can be withstood by the neoprene gasket, while the maximum deformation is used to evaluate the geometry or dimension of the gasket. The result shows that the maximum contact stress in the gasket is 0.218 MPa at 20 N.m of bolt torsion, while the maximum deformation is 7.1942 mm in the Y axis which occured at 20 N.m of bolt torsion. The maximum deformation of the gasket does not interfere with the bolt position hence this condition is accepted for real application. Based on the current theory and the simulation results, the maximum internal fluid pressure that can be resisted should be less than 0.218 MPa otherwise the fluid will leak across the gasket.

Keywords: *Polymer gasket; thermal stress; FE simulation; ANSYS*

1. Introduction

Polymers have been widely used as seal elements or gaskets and play an important role in many industries such as automotive industries, oil and gas industries, food and beverage, etc. Polymers are used extensively in many industries because of their availability and the low cost production. They are also used for their outstanding damping and energy absorption characteristics, flexibility, long service life, their resistance against moisture, heat, and pressure, non-toxic properties, moldability, and variable stiffness.

In this paper, a kind of polymers which is a neoprene rubber is used as a gasket in a bolted joint connection. Eventhough the geometry of this gasket is quite simple but the nonlinear material property of the neoprene rubber requires relevant literatures and the experiments are costly and difficult. With the aid of the hyper-elastic modul in ANSYS software, this paper simulated and obtained the result of the sealing performance of the gasket by analyzing the maximum contact stresses and deformations with different tightening bolt torsion.

Some researchers investigated about the polymer rubber characteristics while other researchers discussed about the effects of the fibers in the silicone or rubber material properties. Persson and Yang [1] introduced percolation theory and contact mechanics theory. Persson and Yang investigated the role of surface roughness in the interface between a rubber and a hard counter surface. Lorenz and Persson [2] experimentally investigated the leak rate of rubber seals and compared the results with the percolation theory and contact mechanics theory. Yang et al. [3] performed finite element simulation and experimental work of the tubular seals rubber composites. Some researchers focused on sealing performance of gaskets. Saeed et al. [5] investigated the Super Seal Gasket using finite element simulation to optimize the geometric model and the dimensions of the gasket. Choiron et al. [6] focused on design optimization based on contact stresses of the corrugated metal gasket. Choiron et al. [7] also evaluated the effects of contact area to leak performance of the corrugated metal gasket based on finite element method. Nurhadianto et al. [8] investigated the effects of forming process during manufacturing phase to contact stresses of the gasket. Haruyama et al. [9] explored the effects of surface roughness to leak performance of the corrugated metal gasket. The other researchers also focus on the finite element method using different software to analyzed the sealing performance of rubber gaskets or rubber seals [10-14].

In summary, the parameters which affect the sealing performance are surface roughness [1,2,9], contact stresses [2-5,7,10-14], contact area [6,8,10] and the internal fluid pressure [1,6,11] which is supplied into the gasket-flange assembly. It can be infer also that if the contact stress is lower than the fluid working pressure then leaks will occur [1,12,13].

The aim of this study is to simulate and analyze the contact stress distribution and the maximum contact stress of the gasket and also to find the maximum deformation (in X,Y and Z axis) of the gasket.

2. Material and method

2.1 CAD Model

The model was designed using SolidWork software before imported into ANSYS Design modeler. Figure 1 depicts the gasket-flange assembly.

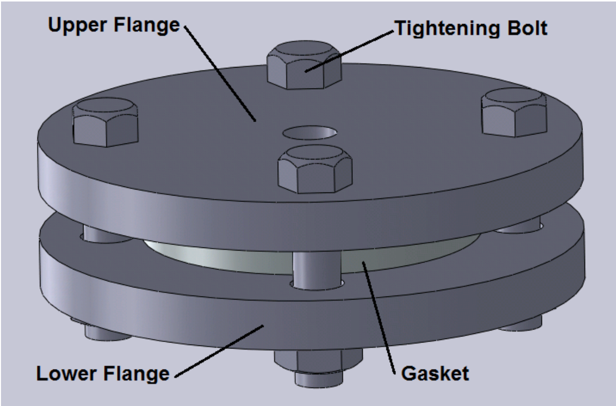

Figure 1: Gasket-flange assembly

The flanges are made of SUS304 stainless steel while the gasket made of the neoprene rubber. Figure 2 shows the detail dimension of the flanges and the gasket.

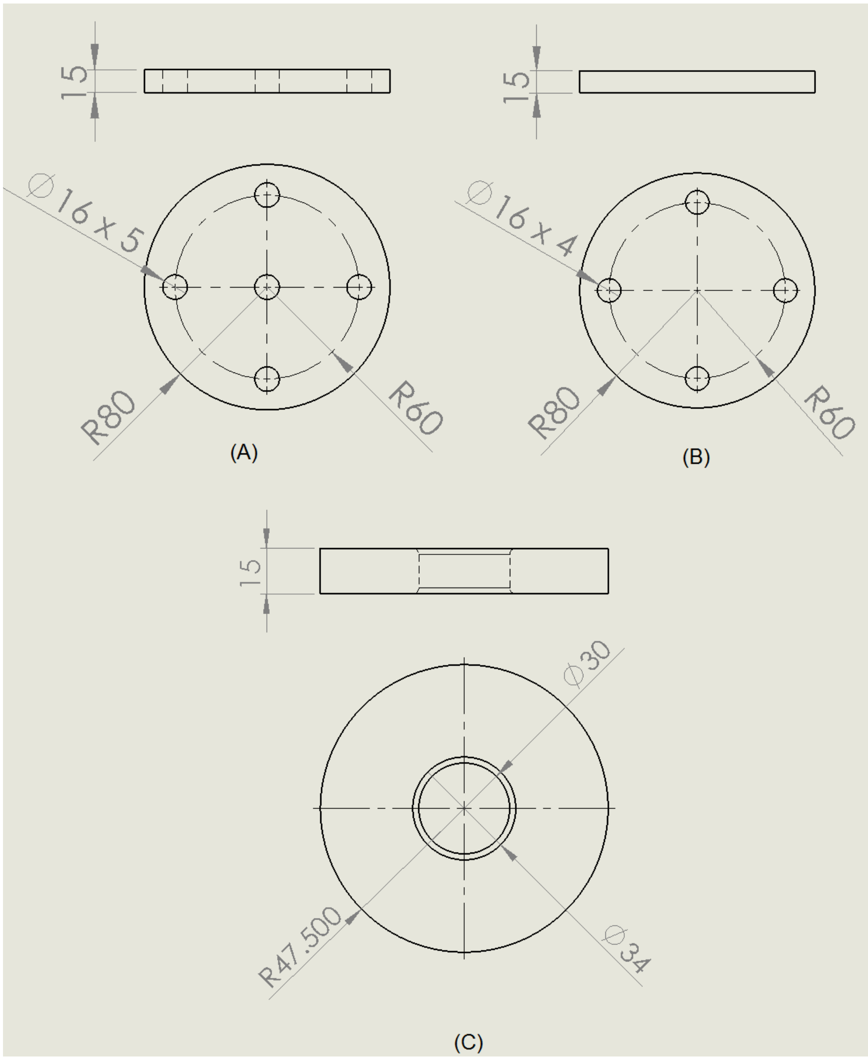

Figure 2: Detail dimensions (A) upper flange; (B) lower flange; (C) gasket

2.2 Material Specification

Table 1 shows the material properties for stainless steel SUS304 while table 2 presents hyperelastic properties of Neoprene Rubber.

Table 1: Properties of SUS304 [13]

Tensile Strength, Ultimate	505 Mpa
Tensile Strength, Yield	215 Mpa
Modulus of Elasticity	193 - 200 Gpa
Elongation at break (%)	70%
Poisson's Ratio	0.29
Shear Modulus	86 Gpa

Table 2: Material Properties of Neoprene Rubber [14]

Density	1.35 - 1.50 g/cc
Hardness, Shore A	35 – 95
Tensile Strength, Ultimate	28.0 Mpa
C10	0.01293 Mpa
C20	-0.000103 Mpa
C30	2.7406E-06 Mpa
Incompressibility Parameter D1	0.1436 MPa^{-1}
Incompressibility Parameter D2	-0.2397 MPa^{-1}
Incompressibility Parameter D3	0.00878 MPa^{-1}

Figure 3 shows the curve fitting for the neoprene rubber using Yeoh 3rd order approach to find the constants C10, C20, C30, D1, D2 and D3.

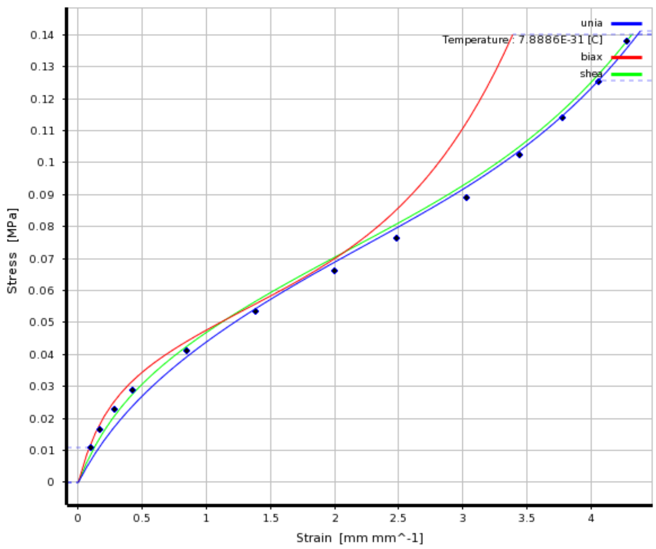

Figure 3: Curve fitting Yeoh 3rd order for Neoprene rubber

2.3 Method

In this paper the modeling and simulation were run in the FE software ANSYS using non-linear hyperelastic module. Figure 4 and 5 show the finite element model for the gasket and flanges.

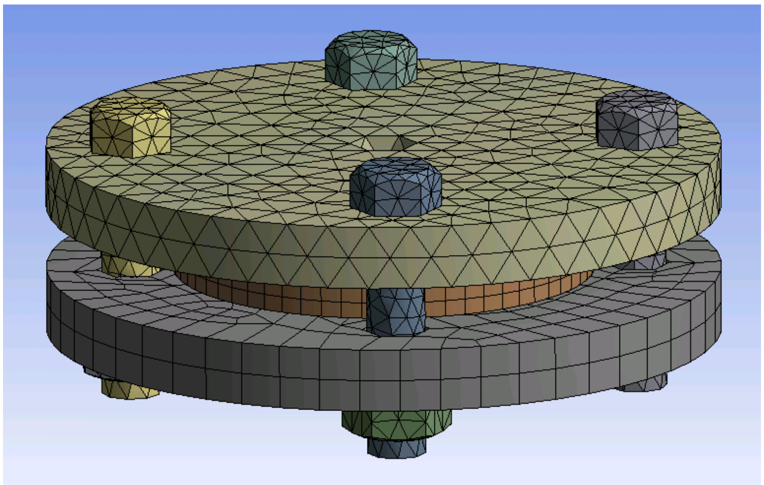

Figure 4: FE model for the gasket- flanges assembly

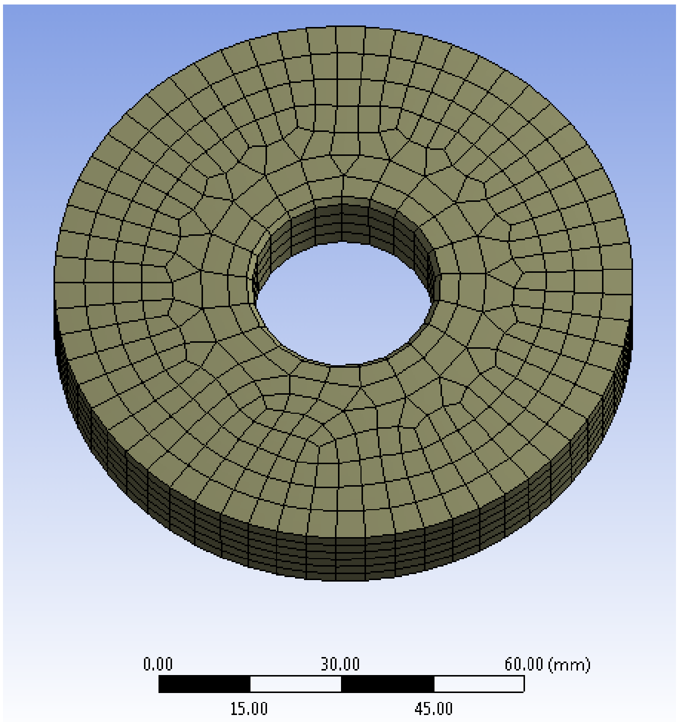

Figure 5: FE model for the gasket

In the simulation, the flange is considered as a rigid body, hence we neglect the stress and deformation on the flanges. The element type used in the gasket is SOLID185 as shown in figure 6.

SOLID185 is commonly used for 3-D modeling of solid structures which defined by eight nodes (node I to node P) having three degrees of freedom at each node i.e. translations of the nodal in the x, y, and z directions as shown in figure 6. The element is also chosen for its hyperelasticity capabilities where it also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. The total number of the gasket elements is 2758 with 3913 nodes.

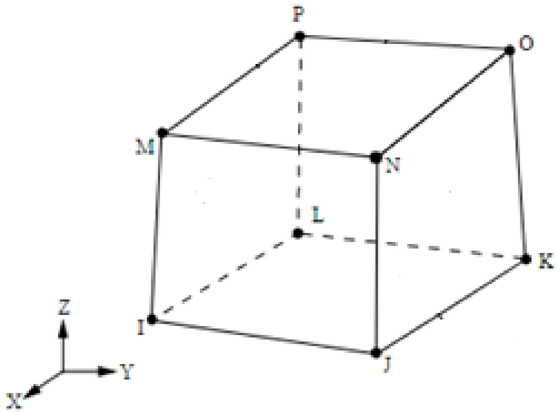

Figure 6: SOLID 185 element topology

In this simulation, 5 steps of loading are carried out in order to simulate the actual working conditions. The loadings are tightening bolt torsion started from 4 N.m, 8 N.m, 12 N.m, 16 N.m, and 20 N.m.

Boundary conditions for the model are set as follows: The lower flange is set to be fixed while the displacement of the lower surface of the gasket is set to be 0 at Z direction. The displacement of the upper flange is set to be free in Z axis and 0 in X and Y axis. Considering that the gasket is a neoprene rubber which is sticky, the contact property between the gasket and flanges is defined as a bonded contact.

3. Result and discussion

3.1 Contact stress

Figure 7 shows the FEA simulation results of the contact stress distribution on the gasket at certain values from 4 N.m to 20 N.m. The figures show that the stress distributions at all torsions are almost similar in term of pattern and only diverse in term of stress level or value. It can be seen also that the maximum stress occurs in the inner edge of the gasket because the geometry at this location represent the critical shape where the critical stress (shown in the red colour) usually occurs.

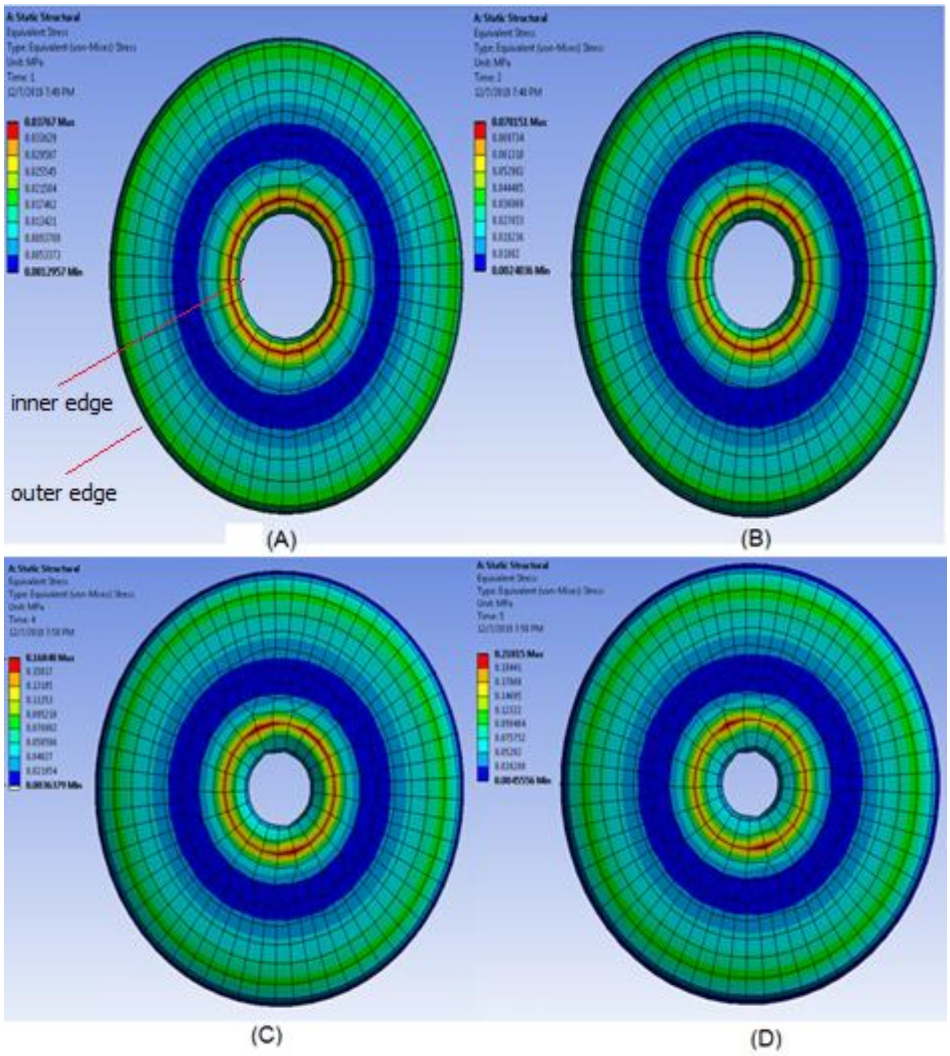

Figure 7: Contact stress distribution (A) at 4 N.m; (B) at 8 N.m; (C) at 16 N.m; (D) at 20 N.m

Figure 8 depicts the maximum contact stress againts the tightenning bolt torsion. It can be seen that the contact stress incerases as the bolt torsion incerases. At 4 N.m bolt torsion, the maximum stress occurs at around 0.04 MPa while at the maximum bolt torsion (20 N.m) the maximum contact stress achieved 0.218 MPa MPa. From the result we can see that the higher load produces higher contact stress, which agree with the result from [1,2,4,6-8,12-14].

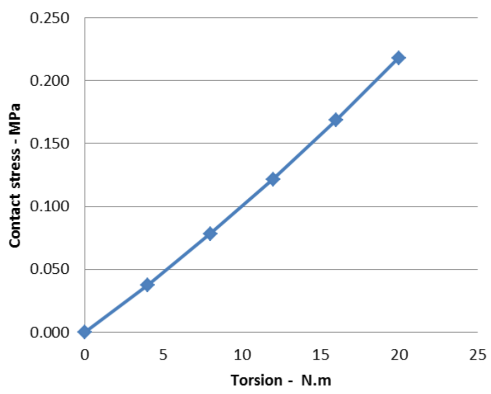

Figure 8: Contact stress vs torsion

3.2 Gasket Deformation

Figure 9 shows the FEA simulation results of the gasket deformation in X-axis, Y-axis and Z-axis, while Figure 10 depicts the maximum deformation of the gasket againts the tightenning bolt torsion. As can be seen, the deformation in all directions incerase as the torsion bolt incerase. The maximum deformation of the gasket in X axis is 7.0143 mm while in Y axis is 7.1942 mm which occured at the maximum torsion 20 N.m. The deformation in these two axes is almost the same considering that the geometry of the gasket represents an axisymetry structure, hence the curves for these axes in the graph almost overlap. The maximum deformation of the gasket in Z axis is 3.905 mm which occured at the maximum torsion 20 N.m.

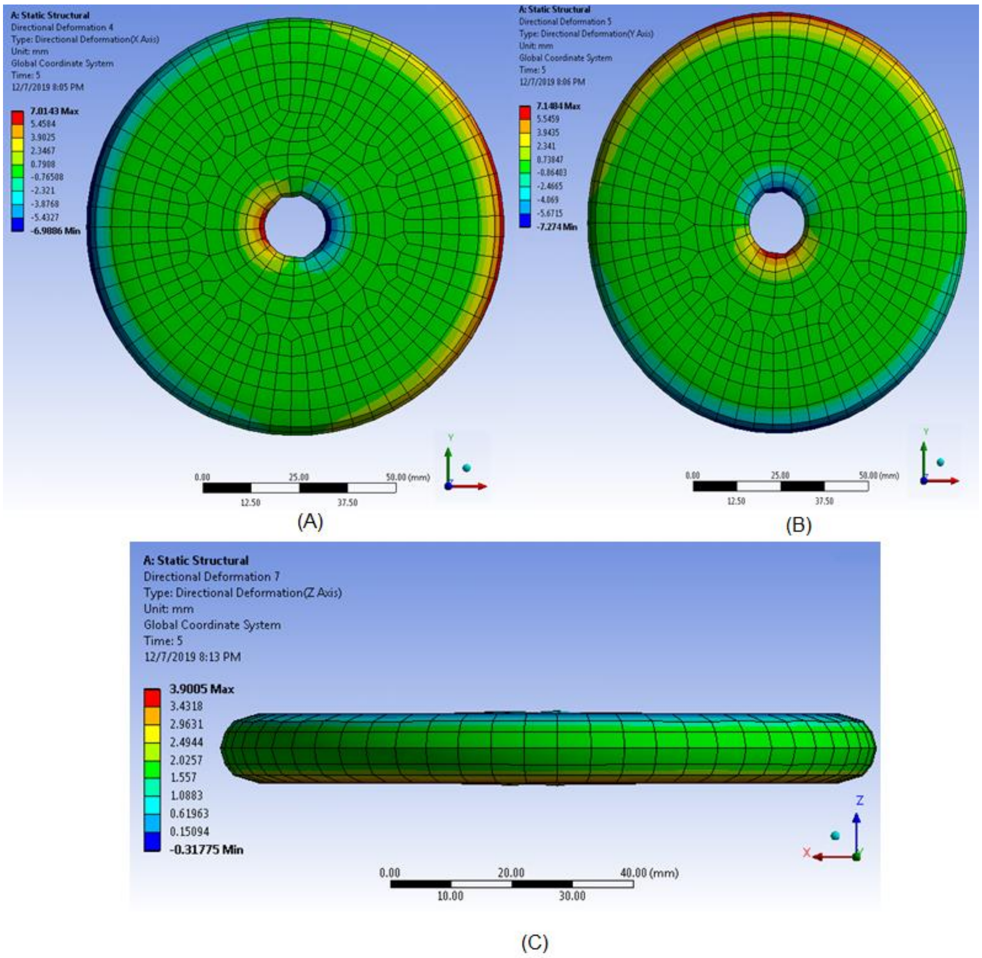

Figure 9: Deformation of the gasket (A) X axis; (B) Y axis; (C) Z axis where the red colour shows the maximum deformation (in X positive axis) and the blue colour shows the minimum deformation (in X negative axis).

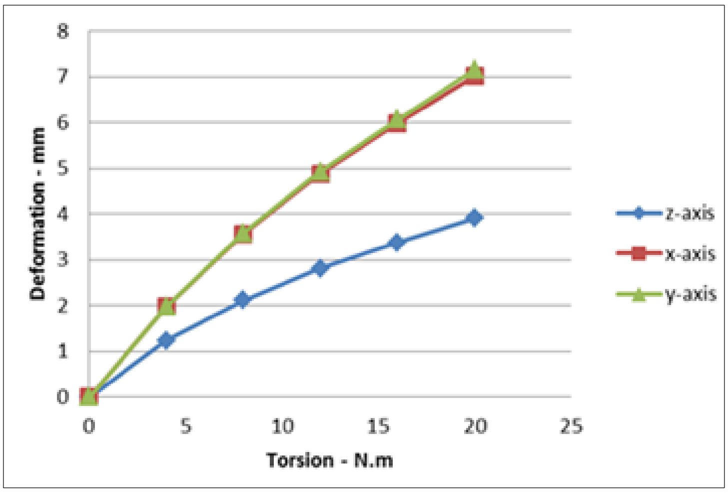

Figure 10: Torsion vs deformation

Figure 11 shows the FEA simulation results of the gasket deformation in Y-axis where the maximum deformation occured. Analyzing the geometry of the model with respect to the bolt position, it can be seen that still there are some gap/ clearance between the deformed gasket and the bolts. At maximum deformation, the gap is 0.31 mm, which indicate that the deformation of the gasket is acceptable. It can predicted that if the bolt torsion is increased the deformation will increase also, then the deformation of the gasket will not be accepted because the gasket interferes the bolt and may cause the gasket damage and causing leaking in the gasket- flanges assembly.

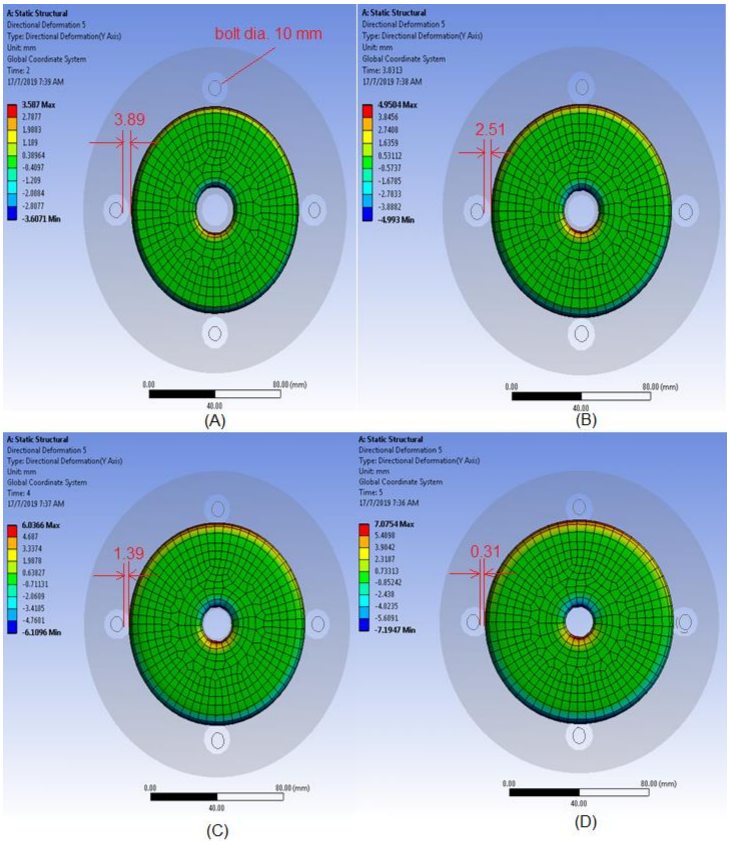

Figure 11: Y axis deformation (A) at 8 N.m; (B) at 12 N.m; (C) at 16 N.m; (D) at 20 N.m

3.3 Validation

The validation for the model and results for the gasket is made based on the force convergence or residual forces value. Figure 12 shows the force convergence during the analysis which consists of 46 substep. It can be seen that at the end of the interation or substep, the force converged and fall below the force criterion value. The force criterion at the end of the substep is 0.6039 N and the foce convergence is 0.1501 N, which indicates that the result calculation for this model is accepted.

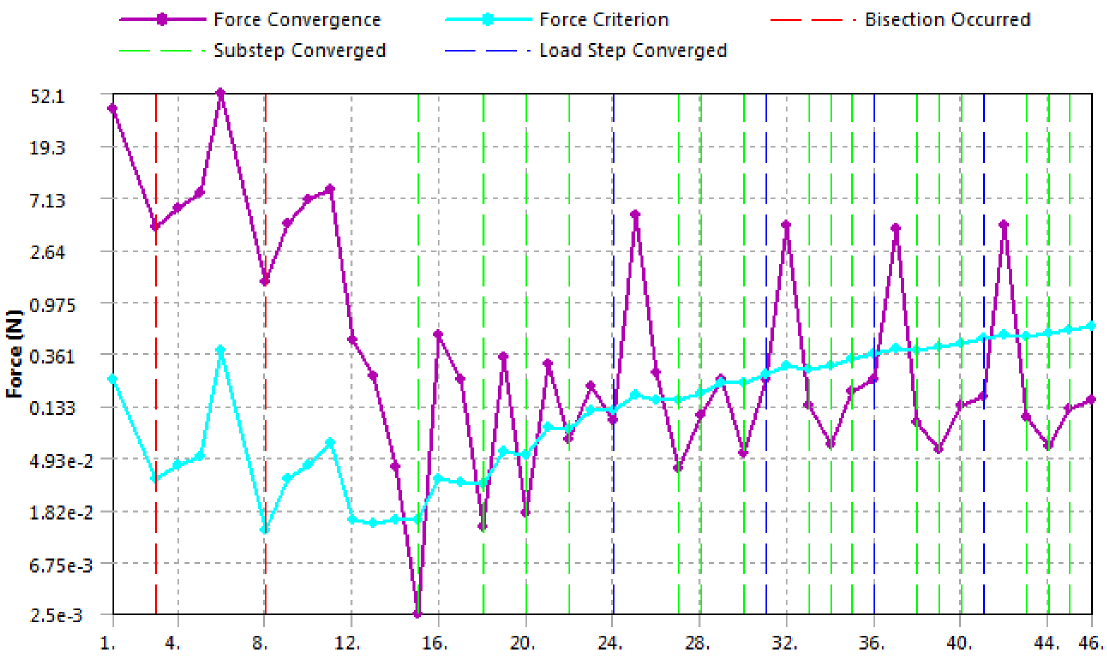

Figure 12: Force convergence for the analysis

4. Conclusion

In this study, the hyperelastic nonlinear neoprene rubber gasket under certain tightening bolt torsion is simulated and investigated. The results are indicated as follows:

a) The maximum contact stress is 0.218 MPa which occured at 20 N.m of the bolt torsion, hence the maximum internal fluid pressure that can be applied to the gasket should be less than 0.218 MPa, otherwise leaking will occur.

b) The maximum deformation is 7.1942 mm occurred in the Y axis which arised at 20 N.m of the bolt torsion. Increasing the torsion bolt to higher value will increase the deformation of the gasket and interferes with the bolt structure and may damage the gasket and causing leaking.

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