Development of 25A-Size Three-Layer Metal Gasket by Using FEM Simulation

Shigeyuki Haruyama, I Made Gatot Karohika, Akinori Sato, Didik Nurhadiyanto, Ken Kaminishi

Abstract**—**Contact width and contact stress are important design parameters for optimizing corrugated metal gasket performance based on elastic and plastic contact stress. In this study, we used a three-layer metal gasket with Al, Cu, Ni as the outer layer, respectively. A finite element method was employed to develop simulation solution. The gasket model was simulated by using two simulation stages which are forming and tightening simulation. The simulation result shows that aluminum with tangent modulus, $Eh_{al} = E_{al}/150$ has the highest slope for contact width. The slope of contact width for plastic mode gasket was higher than the elastic mode gasket.

Keywords**—**Contact width, contact stress, layer, metal gasket, corrugated, simulation.

I. Introduction

ASBESTOS gaskets are very effective for the prevention of leakage and are commonly used in pressure vessels and piping systems in many industries. However, asbestos is an extremely dangerous chemical substance, which can cause serious illnesses. There have been some research works on 25A corrugated metal gasket as an asbestos replacement. Saeed et al. [1] found that contact width and contact stress were an important design parameter to optimize the 25A corrugated metal gasket. Haruyama et al. [2] investigated the limit size of contact width as 25A size metal gasket design parameter.

In this study, the quantitative evaluation of helium leak rate and contact width of gasket which has no leak by water pressure test had been cleared. From the above matter, contact width can be used as a main parameter to optimize the gasket design. The leakage can be reduced with increasing the contact width. Choiron et al. [3] studied a validity method using pressure sensitive paper for gasket contact width and shown the similar trend data between experiment and simulation. Nurhadiyanto et al. [4] optimize the gasket based on an elastic contact stress (0-MPa mode) and plastic contact stress (400-MPa mode) considering forming effect. The research found that gasket 400-MPa mode design better than gasket 0-MPa mode based on helium leak test. The Helium leak test shows that gasket 0-MPa mode did not leak on the 100 KN axial load while the gasket 400-MPa mode did not leak on 80 KN axial load. Haruyama et al. [5] include surface roughness effect of the flange and found that the smoother surface roughness of the flange would have the higher slope for force per unit length.

Results from a previous study above determined using a single material SUS304. The single material gasket can only form a macro seal due to the surface finish of the flanges and because that would reduce the ability of sealing gaskets. From previous study [5], it is also known that high axial forces are still required, which are 80, 100, 120 KN to prevent leakage and for 0-MPa, surface roughness 3.5 micrometer is still leaking. Further development is needed for gasket material with sufficient stiffness, but the outermost layer is softer than base material so that it will cover the flange surface roughness. Based on that, this research proposed three-layer metal gasket with surface layer properties softer than the base metal; therefore, increase seal ability between contacting surfaces. The three layer material with SUS304 as base metal and the surface layer (Al, Cu, Ni) that is softer than base metal was chosen so that when contact with flanges it will form the micro seal to cover roughness of the flange.

The aim of this research is to determine the effect of a different material layer and tangent modulus material layer in three layer metal gasket to minimize leakage. The leakage can be associated with contact width and contact stress. Contact width and contact stress determined by simulation analysis based on an elastic and plastic condition.

II. Material and Method

The gasket used in this research is circumference beads gasket. The shape of gasket is produced by mold press. Three layer sheet metals assumed to be fully bonded; consequently, the interface delamination is beyond the scope of this paper. The dimension of gasket based on a previous study [5] with thickness (T) 1.2 mm for elastic mode, 1.5 mm for plastic mode and length (L) 19.5 mm (Fig. 1). In this study, the thickness of the surface layer (t_2) was 0.1 mm. The base material (SUS304) has a characteristic modulus of the elasticity (E_{sus304}) of 210 GPa, the nominal stress (σ_{sus304}) of 398.83 MPa, tangent modulus of 1900.53 MPa. Aluminum (Al) has a characteristic modulus of the elasticity (E_{al}) of 75 GPa, the nominal stress (σ_{al}) of 75 MPa, tangent modulus ($Eh_{al} = E_{al}/50$, $E_{al}/100$, $E_{al}/150$). Nickel (Ni) has a characteristic modulus of the elasticity (E_{ni}) of 205GPa, the nominal stress (σ_{ni}) of 205MPa, tangent modulus ($Eh_{ni} = E_{ni}/50$, $E_{ni}/100$, $E_{ni}/150$). Copper (Cu) has a characteristic modulus of the elasticity (E_{cu}) of 136GPa, the nominal stress (σ_{cu}) of 136MPa, tangent modulus (Eh_{cu} =

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$E_{cu}/50$, $E_{cu}/100$, $E_{cu}/150$). Aluminum (Al), Copper (Cu) and Nickel (Ni) can be clad well with stainless steel in all shapes and sizes [6]. In the next, gasket with a layer of aluminum (Al), nickel (Ni) and copper (Cu) we called as Al/SUS304/Al, Ni/SUS304/Ni, and Cu/SUS304/Cu, respectively.

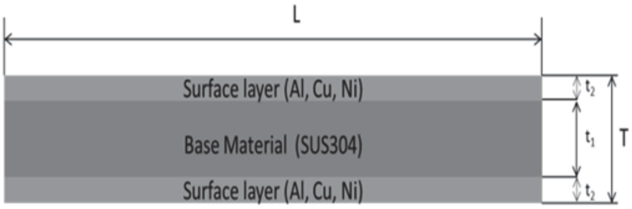


Fig. 1 Three layer clad metal sheet design

In [4], the gasket design based on contact status, without considering distribution of stress called 0-MPa mode. Otherwise, the gasket design by deleting the contact stress values below 400MPa called 400-MPa mode. In this study, the gasket design based on an elastic condition of the surface metal namely gasket elastic mode. The gasket design based on a plastic condition of the surface metal is gasket plastic mode. It is by deleting the contact stress values below of the nominal stress of surface metal, which are Al, Cu, Ni.

In this study, a gasket model is divided into two simulation stages by using forming and tightening simulation. Flowchart of the stage simulation gasket by considering the thickness of the metal surface, tangent modulus effects is shown in Fig. 2. The deformation mode of the stainless gasket was investigated using an FEM analysis. The stages were modeled using the software MSC. Marc [7]. First, using two-dimensional assumptions, an axis-symmetric model was adopted for the forming process simulation in the axial direction between the upper and lower dies. Second, the gasket shape produced by mold press then compressed in axial direction between the upper and lower flanges to simulate the relationship between the axial force, average contact stress and contact width curves. Both the upper and lower flanges are assumed to be rigid bodies. Further, the contact stress and contact width evaluation were performed only for the convex portion of the gasket, which is effective at reducing the leakage. The forming and tightening simulation setting up is shown in Fig. 3

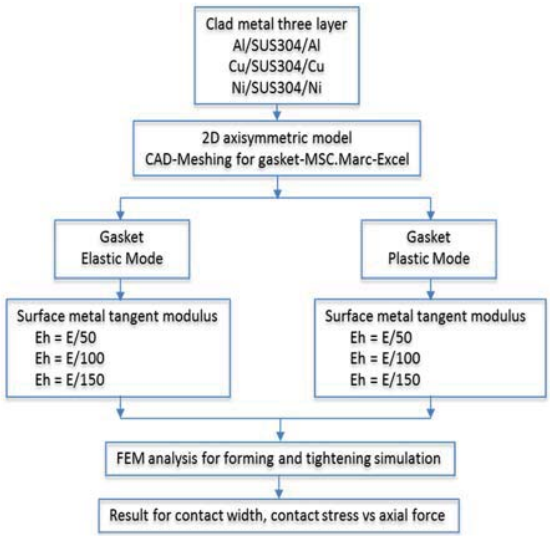


Fig. 2 Flowchart the stage of the three layer gasket simulation

III. Result and Discussion

Based on [5], [6], peak 2 and peak 3 were higher than peak 1 and peak 4 for contact width and contact stress. Therefore, in this study, the upper contact and lower contact of three layer gasket will be represented by peak 3 and peak 2, respectively.

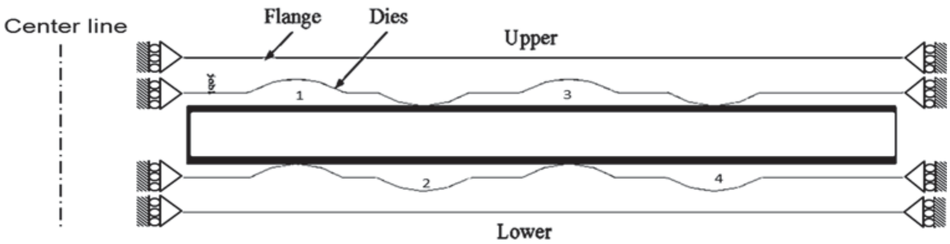
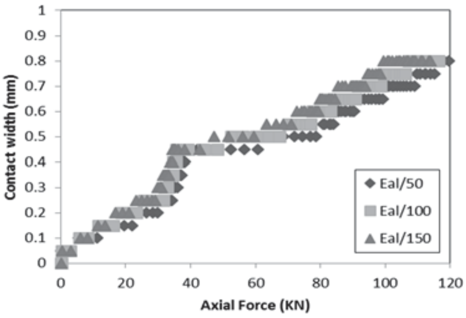


Fig. 3 Three layers Gasket simulation setting up

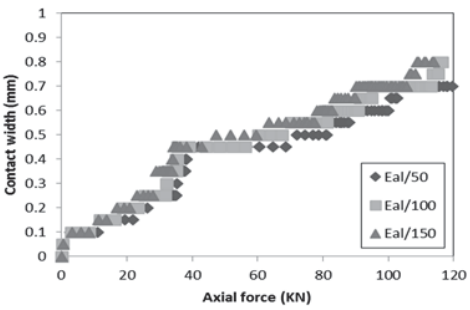
Fig. 4 shows the simulation result for upper and lower contacts of the gasket Al/SUS304/Al in an elastic mode for the contact width. This figure shows that contact width increases with axial force. The contact width of a gasket Al/SUS304/Al with tangent modulus, $Eh_{al} = E_{al}/150$ and $Eh_{al} = E_{al}/50$ had the highest and the lowest slope, respectively.

Fig. 5 shows the simulation result for the upper and lower contacts of gasket Al/SUS304/Al in an elastic mode for the average contact stress. Gasket Al/SUS304/Al has tangent modulus $Eh_{al} = E_{al}/50$ showed the highest average contact stress propensity than the others. To maintain seal integrity, the effective compressive pressure on gasket must be higher than the internal pressure by some multiple. Usually, the value of internal pressure in the piping system is around 10 MPa. Fig. 5 denoted that the contact stress value was around 350 MPa at 100 KN. It is larger enough to reduce the internal pressure effect, which is 35 times internal pressure.

Fig. 6 shows the simulation result for upper and lower contacts of the gasket Cu/SUS304/Cu in an elastic mode for the contact width. This figure shows that contact width increases with axial force. The contact width in a gasket Cu/SUS304/Cu in contact with the flange which has a tangent modulus, $Eh_{cu} = E_{cu}/150$ and $Eh_{cu} = E_{cu}/50$ had the highest and the lowest slope, respectively.

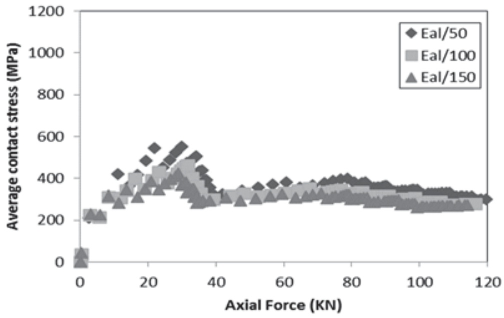


(a) Upper contact

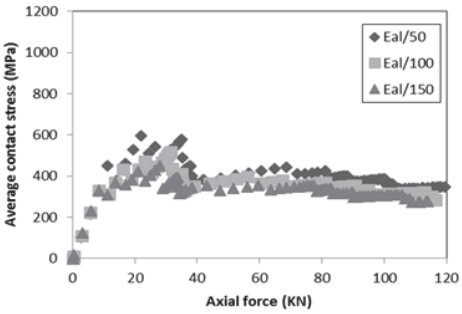


(b) Lower contact

Fig. 4 Contact width for gasket Al/SUS304/Al in elastic mode

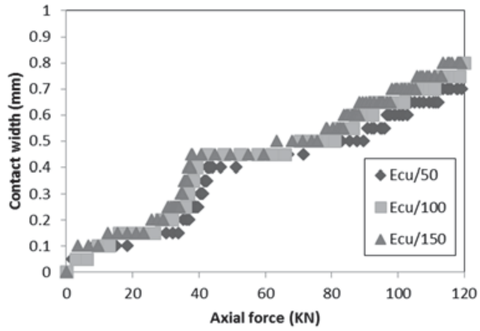


(a) Upper contact

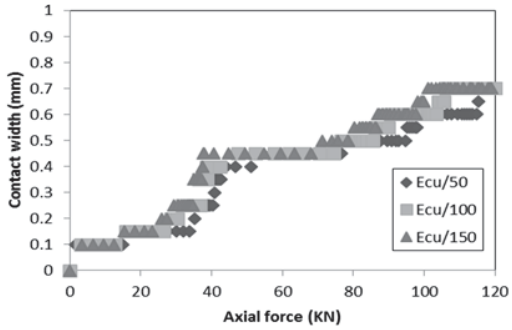


(b) Lower contact

Fig. 5 Average contact stress for gasket Al/SUS304/Al in elastic mode

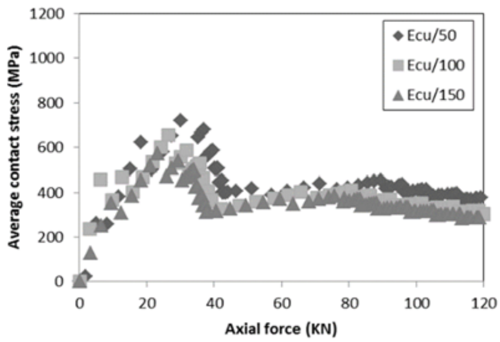


(a) Upper contact

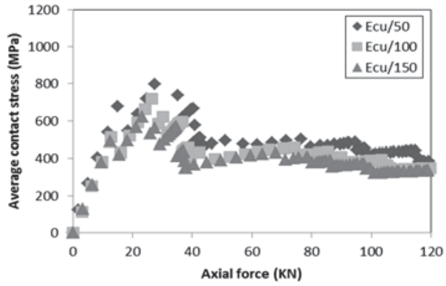


(b) Lower contact

Fig. 6 Contact width for gasket Cu/SUS304/Cu in elastic mode



(a) Upper contact



(b) Lower contact

Fig. 7 Average contact stress for gasket Cu/SUS304/Cu in elastic mode

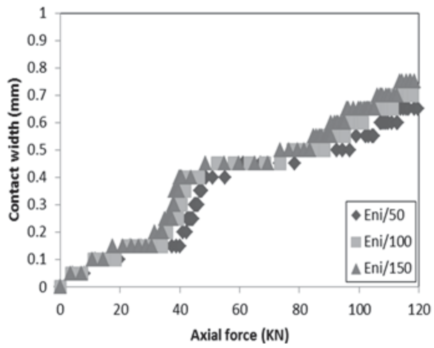
Fig. 7 shows the simulation result for the upper and lower contacts of gasket Cu/SUS304/Cu in an elastic mode for the average contact stress. The contact stress occurs in the gasket contact with flange all in the upper and lower contact is similar. But, gasket Cu/SUS304/Cu with tangent modulus $Eh_{cu} = E_{cu}/50$ showed the highest propensity than the others. The average contact stress for gasket Cu/SUS304/Cu $Eh_{cu} = E_{cu}/150$ was the lowest. Fig. 7 denoted that the contact stress value was around 410 MPa at 100 KN. It is larger enough to reduce the internal pressure effect, which is 41 times internal pressure.

Fig. 8 shows the simulation result for upper and lower contacts of the gasket Ni/SUS304/Ni in an elastic mode for the contact width. This figure shows that contact width increases with axial force. The contact width of a gasket Ni/SUS304/Ni with tangent modulus, $Eh_{nil} = E_{ni}/150$ and $Eh_{ni} = E_{ni}/50$ had the highest and the lowest slope, respectively.

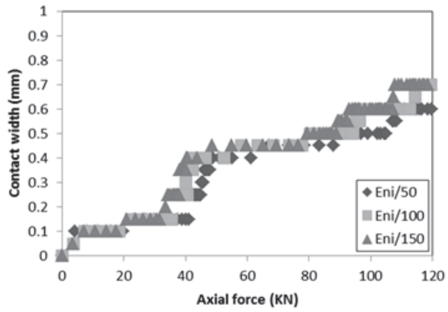
Fig. 9 shows the simulation result for the upper and lower contacts of gasket Ni/SUS304/Ni in an elastic mode for the average contact stress. The contact stress occurs in the gasket contact with the flange all in the upper and lower contact is similar. But, gasket Ni/SUS304/Ni with tangent modulus $Eh_{ni} = E_{ni}/50$ showed the highest propensity than the others. The average contact stress for gasket Ni/SUS304/Ni $Eh_{nil} = E_{ni}/150$ was the lowest. Fig. 9 denoted that the contact stress value was around 500 MPa at 100 KN. It is larger enough to reduce the internal pressure effect, which is 50 times internal pressure.

Fig. 10 shows the simulation result for upper and lower contacts of the gasket Al/SUS304/Al in a plastic mode for the contact width. This figure shows that contact width increases with axial force. The contact width of a gasket Al/SUS304/Al with tangent modulus, $Eh_{al} = E_{al}/150$ and $Eh_{al} = E_{al}/50$ had the highest and the lowest slope, respectively.

Fig. 11 shows the simulation result for the upper and lower contacts of gasket Al/SUS304/Al in a plastic mode for the average contact stress. The contact stress occurs in the gasket contact with flange all in the upper and lower contact is similar. But, gasket Al/SUS304/Al which tangent modulus $Eh_{al} = E_{al}/50$ showed the highest propensity than the others. The average contact stress for gasket Al/SUS304/Al $Eh_{al} = E_{al}/150$ was the lowest. Fig. 12 denoted that the contact stress value was around 480 MPa at 80 KN. It is larger enough to reduce the internal pressure effect, which is 48 times internal pressure.

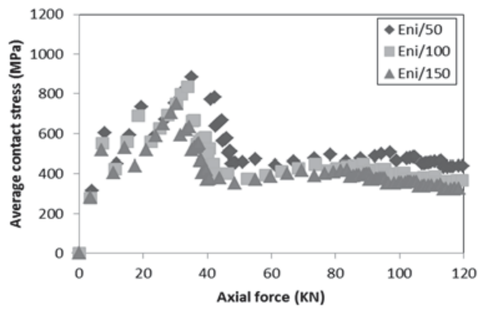


(a) Upper contact

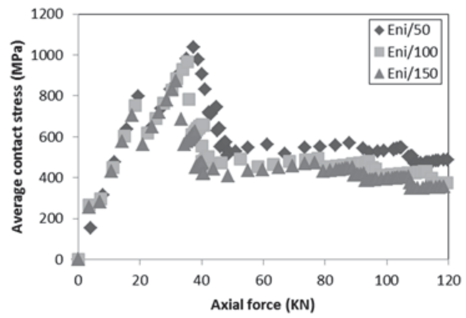


(b) Lower contact

Fig. 8 Contact width for gasket Ni/SUS304/Ni in elastic mode

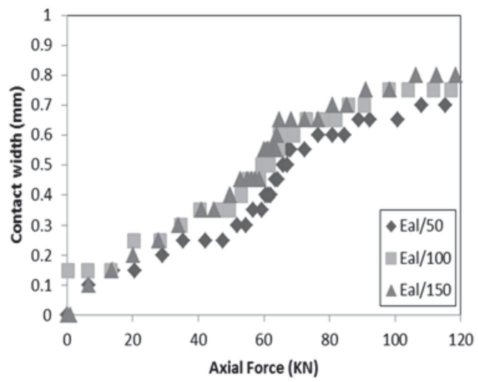


(a) Upper contact

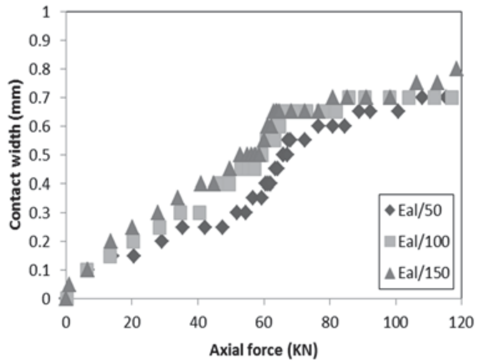


(b) Lower contact

Fig. 9 Average contact stress for gasket Ni/SUS304/Ni in elastic mode

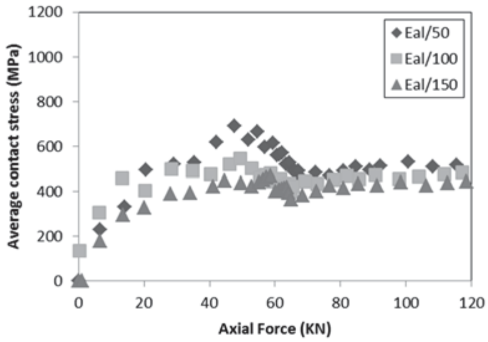


(a) Upper contact

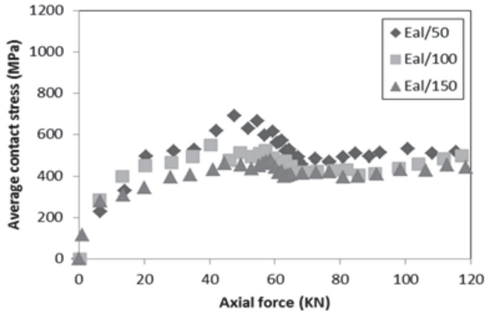


(b) Lower contact

Fig. 10 Contact width for gasket Al/SUS304/Al in plastic mode

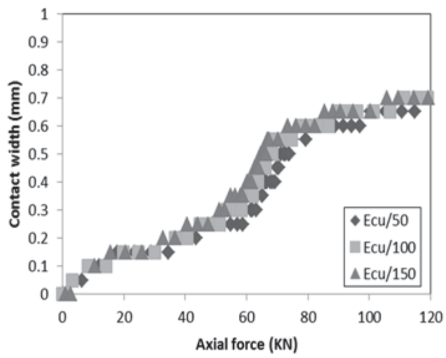


(a) Upper contact

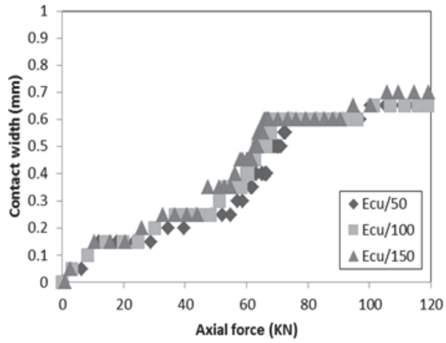


(b) Lower contact

Fig. 11 Average contact stress for gasket Al/SUS304/Al in plastic mode

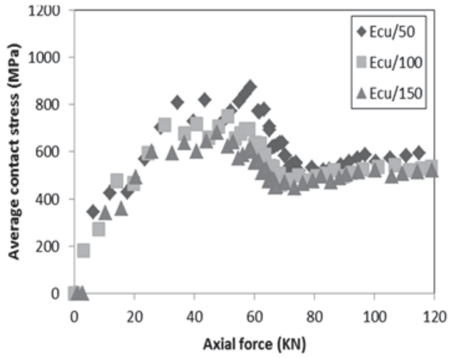


(a) Upper contact

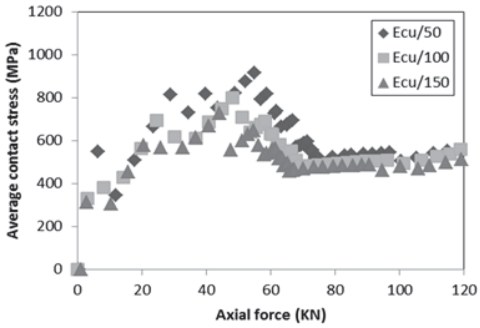


(b) Lower contact

Fig. 12 Contact width for gasket Cu/SUS304/Cu in plastic mode



(a) Upper contact



(b) Lower contact

Fig. 13 Average contact stress for gasket Cu/SUS304/Cu in plastic mode

Fig. 12 shows the simulation result for upper and lower contacts of the gasket Cu/SUS304/Cu in a plastic model for the contact width. This figure shows that contact width increases with axial force. The contact width in a gasket Cu/SUS304/Cu in contact with the flange which has a tangent modulus, $Eh_{cu} = E_{cu}/150$ and $Eh_{cu} = E_{cu}/50$ had the highest and the lowest slope, respectively.

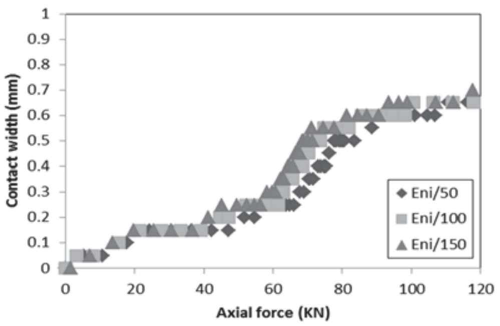
Fig. 13 shows the simulation result for the upper and lower contacts of gasket Cu/SUS304/Cu in a plastic mode for the average contact stress. The contact stress occurs in the gasket contact with flange all in the upper and lower contact is similar. But, gasket Cu/SUS304/Cu with tangent modulus Ehcu = Ecu/50 showed the highest propensity than the others. The average contact stress for gasket Cu/SUS304/Cu Ehcu =

Ecu/150 was the lowest. Fig. 13 denoted that the contact stress value was around 520 MPa at 80 KN. It is larger enough to reduce the internal pressure effect, which is 52 times internal pressure.

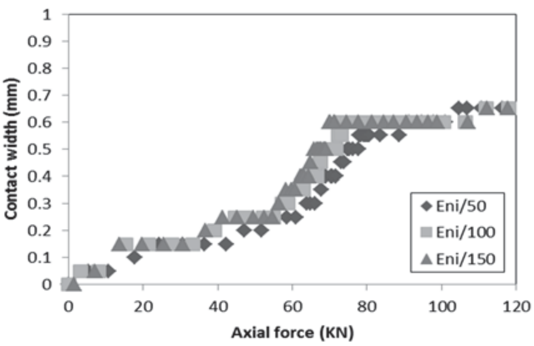
Fig. 14 shows the simulation result for upper and lower contacts of the gasket Ni/SUS304/Ni in a plastic mode for the contact width. This figure shows that contact width increases with axial force. The contact width in a gasket Ni/SUS304/Ni in contact with the flange with tangent modulus, Ehnil = Eni/150, and Ehni = Eni/50 had the highest and the lowest slope, respectively.

Fig. 15 shows the simulation result for the upper and lower contacts of gasket Ni/SUS304/Ni in a plastic mode for the average contact stress. The contact stress occurs in the gasket contact with flange all in the upper and lower contact is similar. But, gasket Ni/SUS304/Ni with tangent modulus Ehni = Eni/50 showed the highest propensity than the others. The average contact stress for gasket Ni/SUS304/Ni Ehnil = Eni/150 was the lowest. Fig. 15 denoted that the contact stress value was around 600 MPa at 80 KN. It is larger enough to reduce the internal pressure effect, which is 60 times the internal pressure.

Based on simulation result, the average contact stress for the gasket elastic mode was lower than the gasket plastic mode. However, the contact width for the gasket elastic mode was higher than the gasket plastic mode. This research shows that the three layer corrugated metal gasket had a good prospect.

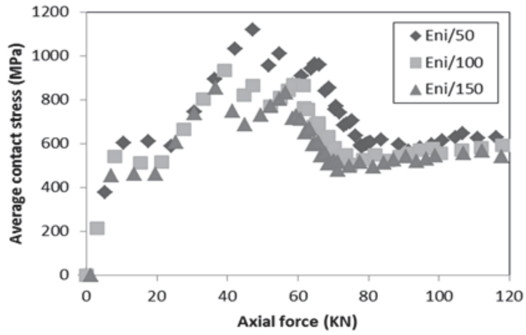


(a) Upper contact

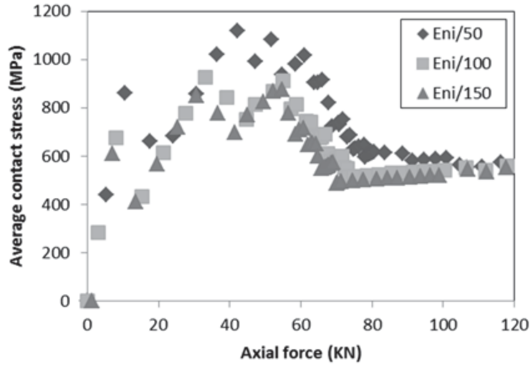


(b) Lower contact

Fig. 14 Contact width for gasket Ni/SUS304/Ni in plastic mode



(a) Upper contact



(b) Lower contact

Fig. 15 Average contact stress for gasket Ni/SUS304/Ni in plastic mode

IV. Conclusion

In this research, from simulation analysis by FEM, we could conclude that:

1) The average contact stress for the gasket elastic mode was lower than the gasket plastic mode. The contact width for the gasket elastic mode was higher than the gasket plastic mode.
2) The average contact stress for gasket Ni/SUS304/Ni which Eh_{ni} = $E_{ni}/50$ showed the highest propensity than the others. The contact width in a gasket Al/SUS304/Al in contact with the flange with tangent modulus, Eh_{al} = $E_{al}/150$ had the highest slope for both kind of gasket.

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