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DEVELOPMENT OF AN A1100 ALUMINUM CORRUGATED METAL GASKETS

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Corrugated metal gaskets (CMG) made from SUS304 have previously been developed, however a coating process with a softer material is necessary for its design to be optimal. The coating process is time consuming and expensive. This research aims to develop CMG from aluminum by simulation analysis and form a CMG design made of aluminum A1100. The method used is development research. The optimum CMG thickness is analyzed using ANSYS Finite Element Analysis (FEA). The control variables being investigated are contact area and contact stress. The independent variable being investigated is the material thickness of CMG. An aluminum gasket is then constructed using a cold-forming process based on the optimum design. The control variables in the leak test are axial force and water pressure. Experiments were also carried out to test the aluminum gasket for leakage. A leakage test is carried out using a water pressure test. Simulation analysis showed results that were in line with experimental leak tests. FEA simulation results show that the optimum gasket thickness is between 3 and 5 mm, with 5 mm being the most optimal. However, CMG with thicknesses of 4 and 5 have similar contact stress and contact area. Leakage test results also show similarities with simulation results. CMG with a thickness of 5 mm has the best performance. The experimental results show that CMG made from aluminum A1100 is suitable for use as a gasket to prevent leakage, it prevents leakage at fluid pressure up to 12 MPa and axial force 100 kN. The results show that aluminum CMG performs on par with SUS304 CMG coated with nickel or copper. This research succeeded in developing CMG made of aluminum

Keywords: gasket development, finite element analysis, corrugated metal gasket, cold forming, aluminum materials, water pressure test

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1. Introduction

Corrugated metal gaskets have been widely developed worldwide to replace toxic asbestos-based gaskets. Saeed et al. developed CMG by developing a metal gasket with two waves. Previous researcher [1] proposed a super seal gasket (SSG), a new CMG measuring 25A that gives a spring effect to the metal and forms a seal line with the flanges. Contact stress and contact width are important design parameters for optimizing gasket performance. CMG consists of two waves at the top and bottom. One wave is to prevent leakage and another wave supports to realize it. This study only stated that the contact width is important, but did not measure the contact width so that no leakage occurs. The next previous study [2] examined the allowable limit of contact width to prevent leakage in CGM using finite element analysis (FEA) and experimental results. Contact width correlates with helium leakage; the more significant the contact width, the better it prevents leakage. This research did not see the forming effect so it did not match reality. The forming effect imparts residual stresses to the gasket material.

The optimum 25A size metal gasket design using FEM simulation based on contact stress, contact width, and forming effects studied by [3]. Plastic gasket designs have better performance than elastic designs. The study did not consider the parameter of surface roughness of the flange. Surface roughness and its effects on gasket leakage were considered by [4]. An increase in gasket leaks is directly proportional to surface roughness value. The high surface roughness of the flange makes the contact between the gasket and the flange not tight. At the contact there is fluid path due to the gap. Previous research [4] also simulated contact width and contact stress on CMG based on surface roughness. The contact width between the flange and the gasket increases on the flange with lower roughness values [5]. The results showed that the high surface roughness value made it difficult to prevent leakage due to the equal material hardness between gaskets and flange. The gasket material cannot fill the flange roughness because both have the same hardness. Previous research [6] solved this problem by adding a thin and softer material layer, forming layers of copper-SUS304-copper. Their analysis found the optimum design gasket in simulation. The contact stress and contact width of the three-layer gasket mentioned earlier investigated by [7]. The results show an increase in contact width by applying a softer, thin layer. However, the copper layer does not bond strongly with SUS304, risking the three-layered gasket coming off. Due to their simultaneous formation through a cold forming process by pressing with a specific amount of force, the copper layer and SUS304 can adhere. The copper layer only sticks to SUS304.

The design of a CMG made of nickel-coated SUS304 by the electroplating method took another approach by conducting a simulation analysis to by [8]. The results show that nickel plating is effective in forming the three-layer CMG. The previous research [9] again examined CMGs coated with nickel and copper by electroplating. The results showed that the gaskets perform well and sealed pipe joint leaks well when measured at high pressure. The next previous study [10] also tested CMG in hot conditions, namely in boilers. The results showed a CMG that performs well at high temperatures. However, the above CMG design incorporates a lengthy process, i.e., forming gaskets and a series of nickel or copper electroplating. Therefore, research on the development of CMG using aluminum material is relevant to replace the CMG material from SUS304 coated by nickel or copper.

2. Literature review and problem statement

The performance of the three-layer metal gasket is affected by the contact width between the gasket surface and the rough flange [11]. It will be simpler to anticipate the performance of the gasket later in the simulation with correct flange roughness modeling. To ascertain how much contact is caused by the rough flange surface, experimental measurements are compared with the surface roughness modeling from the simulation. Real contact width measurement experiment using digital microscope and simulation using finite element software. Measurements between the experimental results and the simulation results of the real surface roughness model reveal that the two are similar. This research did not up to the leakage test experiment. Therefore, it is necessary to do experiments on gasket leaks.

The paper [12] studied the ability of a three-layer corrugated metal gasket to prevent leakage when the outer layer thickness and flange roughness are adjusted. The leakage rate was tested using the helium leakage quantity test experimentally. The gaskets are constructed with oxygen-free copper (C1020) as the outer layer and SUS304 as the base layer and are arranged in a three-layer pattern without bonding. A three-ply corrugated metal gasket showed a better ability to prevent leakage than a single gasket, i. e., a low axial force of 40 kN for all surface roughness tests did not leak. In terms of sealing, three-layer gaskets with a low thickness ratio work well. The three-ply gasket was unaffected by the flange's surface roughness. The problem was that the three layers did not stick together perfectly because there is no bond between the layers.

The paper [13] studied the corrugated gasket's capacity to handle changing load temperatures is greatly enhanced by the application of a shape memory alloy. This study found that the great influence of gasket thickness on leakage. Under installation and operating conditions, corrugation contact pressure increases with increasing sheet thickness (T) and corrugated gasket height (H), showing a decreasing trend with increasing pitch (P). The factors affecting the average corrugated gasket contact pressure are sheet $T > H > P$.

The gasket performance is significantly impacted by the mechanical gasket contact surface leakage channel. First, the fractal characteristics of the spinning and stationary rings were used to determine the initial sealing interface porosity. The fractal form of contact between the two objects which causes the path to open with air will cause porosity. This fractal also causes leakage because the fluid will move through the path. On the porosity of the sealing interface, the impacts of fractal parameters, material qualities, and surface pressure are revealed. The rotating and stationary ring fractal parameters were used to create the initial sealing and loading interface porosity expressions. Greater porosity is present in gasket surfaces with larger fractal dimensions [14]. In the article [15], a theoretical model for calculating metal-to-metal seal leakage rates is examined. This model is based on the fractal theory of porous media, which may accurately describe the impact of the sealing surface's topography from a microscopic viewpoint. The findings demonstrated that the intrinsic characteristics of the pore space and the leakage rate of metal-to-metal gasket were significantly influenced by the parameters of the sealing surface topography. In instance, the rate of metal-to-metal gasket leakage decreases with smoother sealing surface. Furthermore, the leakage rate reduces as the contact pressure rises, and the gasket effectiveness will be significantly compromised if the fluid pressure differential is too considerable.

A simulation technique and a hybrid strategy were used in study [16]. A statistical design of experiment has been used to examine how metal gaskets, flanges, and bolts affect the effectiveness of sealing. The distribution of the bolts and their corrugated shape had the largest impact on the bolts' axial force range and gasket pressure distribution, according to the data.

High gasket stiffness increases contact stress but complicates the cold forming process. The hard surface of the gasket in contact with the hard surface of the flange also causes a small contact width [5]. To prevent leakage, high contact stress and large contact width are required. To increase the contact width, it is necessary to cover the outer surface of a softer material. Besides that, the soft material will fill the roughness of the flange surface [4].

The earlier study [10] looked at CMGs that had been electroplated with nickel and copper once more. The outcomes demonstrated that, when assessed at high pressure, gaskets function effectively and sealed pipe joints leak properly. Leakage was measured using a water pressure test at room temperature. This CMG needs to be tested on actual pipe use, namely in boilers or on pipelines that flow chemical liquids.

The paper [11] was developed for CMG made from SUS304 coated nickel or copper. This CMG has a very good performance in preventing water and gas leaks in boiler channels. CMG is also corrosion and heat resistant up to 200 °C. Visually, this CMG looks nicer because it is plated with copper or nickel which is shinier than the base material, i. e. SUS304. However, this CMG has problems in the relatively long manufacturing process, i. e. gasket material forming process to become CMG and electroplating process to coat CMG. In addition, the possibility of layer damage is relatively easy to occur.

Therefore, it is necessary to develop CMG made from materials softer than SUS304 while being temperature and chemical resistant. The compression resistance performance of corrugated metal gaskets, particularly stainless steel gaskets, is significantly influenced by the manufacturing process. Based on this, the impact of structural parameters related to mechanical qualities on corrugated metal gaskets is examined. Pitch, lip height, and material thickness are important structural factors that influence the characteristics of corrugated metal gaskets [17]. The selected material this research is aluminum A1100.

This research aims to engineer a CMG with a softer substitute material, namely aluminum A1100. This design retains the same relative rigidity as the CMG made from SUS304, by changing the thickness of the aluminum AL1100. The rigidity of CMGs will provide high contact stress. Aluminum A1100 material is softer than SUS304, so it will fill the flange surfaces' roughness and prevent leakage.

3. The aim and objective of this study

The aim of the study is to develop CMG from aluminum A1100 material by simulation and experiment analysis.

To achieve this aim, the following objectives are accomplished:

– to determine the contact stress and contact area by simulation analysis using ANSYS software;

– to know the best thickness of aluminum A1100 material to produce CMG;

– to investigate the leakage performance of CMG made from aluminum A1100 when used to connect pipe flanges;

– to know the maximum pressure that CMG withstand the leakage.

4. Material and methods of research

4. 1. Object and hypothesis of the study

The object of research is corrugated metal gasket made from aluminum A1100. The gasket material was cold formed with a maximum force of 120 tons using a die to form CMG. CMG's performance was tested using a water pressure leak test.

The main hypothesis of the study is CMG is able to withstand leaks at a water fluid pressure of 12 MPa using a certain tightening force. The tightening force is obtained from the bolt.

Assumptions made in the work are gasket leakage was carried out on a laboratory scale at room temperature. Water can represent another fluid as a liquid material in industry. The pipe-flange-gasket system is assumed to represent the pipe-flange-gasket in the industry.

Simplification adopted in the work is a leak test using a water pressure test. Water is pumped into the space between the two flanges attached to the gasket. Under the flange is put white paper, if there is a leak, water will seep through the gaps in the gasket and drip onto the white paper.

4. 2. Material

A1100 aluminum is used as a gasket material because of its effectiveness in high-temperature and high-pressure environments. Its material properties are determined through tensile stress tests based on JISZ2241 [18], yield strength, Young's modulus (E), and Young's tangent modulus. The characteristics of aluminum A1100 material are shown in Table 1 based on data [19].

Table 1

Material properties of Aluminum A1100

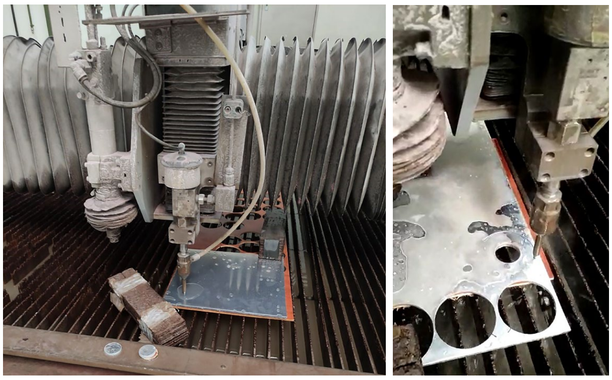
Properties	A1100
Yield strength	105 MPa
Young's modulus	68.9 GPa
Tangent Young's modulus	69 MPa
Poisson ratio	0.33

From the Table 1, it is possible to be concluded mechanical qualities of aluminum A1100 is available to be material of CMG. The modulus of elasticity is lower than SUS304, so the thickness of the material must be thicker.

4. 3. Forming process

The development of the aluminum A1100 corrugated gasket was carried out in two stages. The first stage is to conduct a finite element analysis (FEA) simulation using ANSYS software. Based on the results of FEA, the best results were obtained as a basis for manufacturing the CMG. The independent variable of this study is the thickness of the gasket material, which has three levels, namely 3 mm, 4 mm and 5 mm. Gasket thicknesses were determined based on initial analysis by conducting a cold-forming test. Another consideration is the availability of aluminum A1100 plate materials on the market. The investigated dependent variables are contact-stress and contact area. The second stage is to make CMG from aluminum A1100 through a cold-forming process at room temperature. Aluminum A1100 material was prepared as a circular aluminum plate with a center hole. Dies were prepared to use in the forming process. The circular profile of the aluminum plates was obtained using water jet cutting. This cutting process ensures no damage to the gasket's surface. Damage to the surface of the gasket, albeit only a scratch, will cause leakage when CMG is installed on the flange. Fig. 1 shows the process of cutting gasket material.

The dies used have been made with dimensions determined as in previous studies [10]. The Taguchi and finite element approaches' optimal dimensioning techniques were used to calculate the die dimensions. The lack of a die fill fault is observed to be reduced with an increase in angle inner radius, according to analysis using MSC Marc Software. As seen in Fig. 2, changes in the angle will alter the radius (R) and lip height (h). This increased angle from θ to θ_1 is different from the initial angle by 0 % (0 %), 5 % (5 %), and 10 % (10 %). The best decrease of the lack of die fill fault was demonstrated by increasing the angle by 10 % [20].



a *b*

Fig. 1. Gasket material cutting process by water jet: *a* – cutting process; *b* – after cutting process

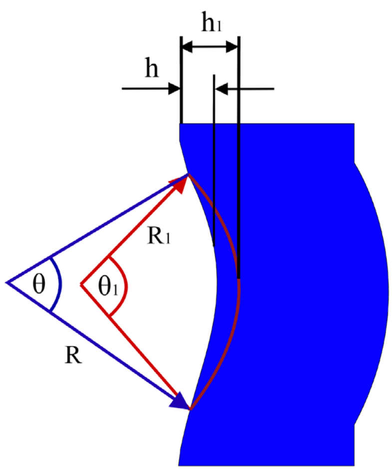
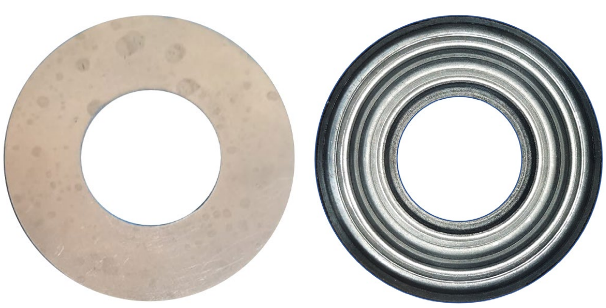


Fig. 2. Adjusting the angle to reduce the defect caused by a lack of die fills on one of the convex contacts

Bohler® K105 stainless steel was used to make the die. The gasket material's corrugation could not be created since the Bohler® K105's 15.3 HRC hardness prevented it. As a result, the material for the dies required additional processing, including hardening. The dies material was heated to 900 °C. The dies will be burning because of how hot it will be. Then, the dies were suddenly submerged in oil and held there until the oil cooled. The die's measured hardness after quenching was 54.1 HRC. The loading in the cold-forming process is carried out three times, based on [21]. The force amount is adjusted to the material characteristics of aluminum A1100. Fig. 3, *a* shows the gasket's blank material, and Fig. 2, *b* shows the CMG that has been formed.



a *b*

Fig. 3. Corrugated metal gasket: *a* – blank material; *b* – corrugated metal gaskets after forming

Gasket materials with a 3 mm, 4 mm, and 5 mm thickness are subjected to a maximum load of 1000 kN, 1050 kN, and 1100 kN, respectively. The loading process starts from zero loads to maximum loading in 60 seconds. The maximum load is held for 30 seconds and then released. To avoid the spring back effect [22], the loading is carried out three times as in the first loading until a corrugated metal gasket is formed.

4. 4. Simulation analysis

Simulation analysis is used to find the optimum dimensions of CMG [23]. The simulation uses ANSYS software to determine the optimal aluminum material thickness before forming it into corrugated metal gaskets. The focus is to have gasket rigidity similar to the previously researched design of the SUS304 CMG as in [9] and [10]. Other dimensions, such as arc radius, arc height, and flat section length, are maintained the same as the SUS304 gasket design. Firstly, the gasket and flange were modeled according to the dimensions and geometry of the JISB2404 [24] and JISB2220 standards [25] using Autodesk Inventor and saved as a universal CAD STEP format. Into the ANSYS software, the material properties of aluminum A1100 (Table 1) were inputted to the Engineering Data, including yield strength, Young's modulus, Young's tangent modulus, and Poisson's ratio. The STEP files of the flange and gasket design were then imported and assigned their designated materials; stainless steel SUS304 and aluminum A1100 for the flange and the gasket, respectively. The next step is to set the connection between objects in the simulation. The flange and gasket are connected by a frictional contact; thus, a frictional coefficient of 0.33 is added. The value of the static friction coefficient is obtained from the friction between aluminum and SUS304 which is in contact without lubrication of 0.61, the dynamic friction coefficient is around 0.3–0.35. When the tightening force is applied, the gasket surface will slide on the flange made from SUS304 so that the coefficient of friction is taken to be 0.33 which is the default from the software. The greater the friction coefficient number will reduce the sliding movement of the gasket back in contact with the flange.

The discretization process of the FEA is carried out by meshing the gasket and the flange geometry into elements, where its size determines the accuracy of the simulation result. The mesh is set with a 0.2 mm sizing for the CMG and the flange, while for the method, it uses quadrilateral elements on both. Fig. 4 shows the results of the gaskets and the flange mesh.

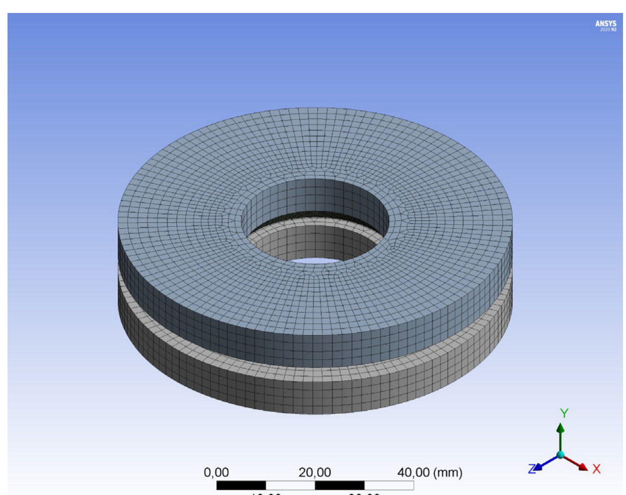


Fig. 4. Meshing of the gasket and the flange

For the result of ANSY FEA, total deformation and equivalent stress are examined. Total deformation informs the deformation of the gasket due to the simulated bolts' tightening force. The equivalent stress tells the stress in the contact area between the flange and the gasket. The contact area is the function of the number of elements with contact stress and the dimensions of the elements [3]. Fig. 5 shows the amount of contact stress in one element.

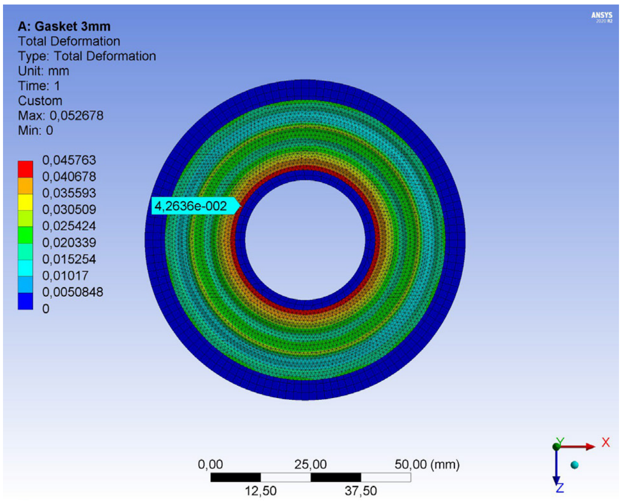
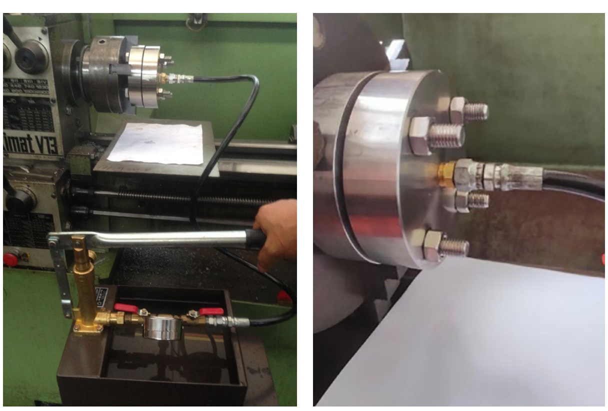


Fig. 5. Contact stress results

Contact stress information in other elements is calculated accordingly. The maximum contact stress and contact area are found in a particular axial force, and the relationship between axial force, contact stress, and contact area can be described.

4. 5. Leak measurement

The subsequent experiment uses a water pressure test to detect gasket leaks. Firstly, the equipment was arranged as depicted in Fig. 6, *a*, in which the equipment is clamped in lathe jaws for robust support. Flanges and gaskets connection is pressed by tightening the bolts. The flange-gasket connection is oriented vertically for ease of leakage detection. This position was chosen so that it is easy to detect water leaks [26]. A sheet of white paper was placed under the connection to detect water leakage, as seen in Fig. 6, *b*.



a *b*

Fig. 6. Leakage test by water pressure test: *a* – applying water pressure; *b* – onset water leakage

Water pressure is controlled by pumping water from the reservoir into the water pressure test system until the desired pressure is reached. The water pressure is measured using a calibrated manometer. The water pressure is variable, namely 5, 7.5, 10, and 12 kgf/cm^2. The tightening force on the bolt is measured using a digital torque wrench. After the specified water pressure is reached, it is left for up to 10 minutes to verify the onset of leakage [10].

5. Result of development of an aluminum A1100 as of corrugated metal gaskets

5. 1. Simulation analysis to get the contact stress and contact

The simulation analysis results show each ridge's contact stress and contact area. The amount of contact stress and contact area in each ridge varies. In the outermost ridge, the gaskets on the upper and lower sides have the same contact stress and contact area characteristics. This ridge's contact stress and contact area are lower than the inner ridges. The outer corrugation serves as a support for the inner ridges. It is the inner corrugations that function as leakage prevention. Therefore, the focus of the discussion of contact stress and the contact area is on the inner corrugation.

Fig. 7–9 show the relationship of the axial force to the contact stress and the contact area of 3 mm, 4 mm, and 5 mm CMGs thicknesses, respectively. It can be seen in the three figures that with an increase in axial force, there is an increase in both contact stress and contact area. The increase is close to the parabolic function with a positive slope ranging from 0 to 120 kN axial force. The maximum axial force of 120 kN is taken from the maximum bolt tightening force. Tightening forces greater than 120 kN is difficult to obtain because the bolts will be damaged.

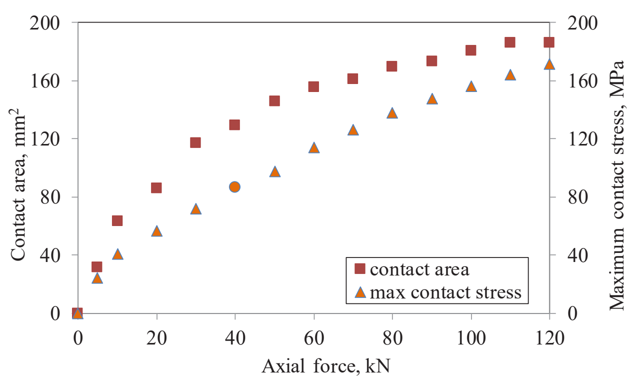


Fig. 7. Relationship between contact area and contact stress to axial force on a 3 mm corrugated metal gaskets

The relationship between contact area and contact stress to axial force on a 3 mm thick CMG is shown in Fig. 7. An increase in axial force will increase contact stress and contact area. This increase is approaching a positive parabolic function. For this thickness, contact stress is relatively low but the contact area is highest than a 4 mm and 5 mm thick CMG. This CMG has relatively lower stiffness, making it unable to press firmly on the flange when an axial force is applied. If axial force is increased to a certain extent, a dent can occur in the CMG. These results are consistent with previous studies [27], where gaskets with low stiffness tend to dent, causing their contact width to shrink. If axial force is added to a certain extent, a dent can occur in the CMG. These results are consistent with previous studies [27], where gaskets with low stiffness tend to dent, causing their contact width to shrink. In the previous study [27], contact width was measured using axisymmetric analysis, whereas this study used a 3-dimensional model. These results show that the 3 mm thick CMG does not have enough stiffness to produce high contact stress. The solution would be to increase the thickness of the gasket material. Fig. 8 shows the simulation results in contact stress and CMG contact width with a thickness of 4 mm.

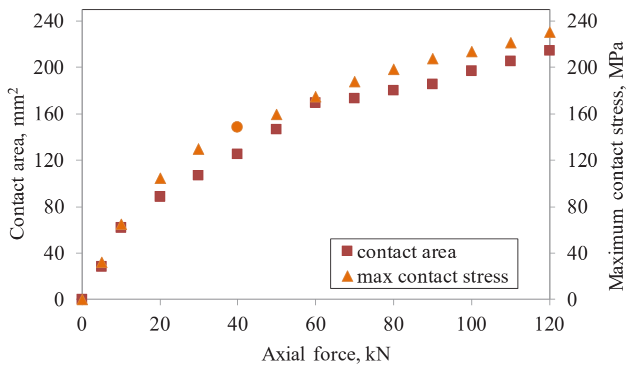


Fig. 8. Relationship between contact area and contact stress to axial force on a 4 mm corrugated metal gaskets

Contact stress increased significantly, and contact area also increased, Fig. 7. The increase in material thickness increases the rigidity of CMG. Again, these results are consistent with the previous studies [27]. The simulation results show that the increase in axial force also increases contact stress and contact area. This increase is also approaching positive parabolic function. The largest contact stress occurred in gaskets with a thickness of 5 mm, depicted in Fig. 9, albeit not much of a difference from the 4 mm gaskets. The contact area was lowest than both another thickness.

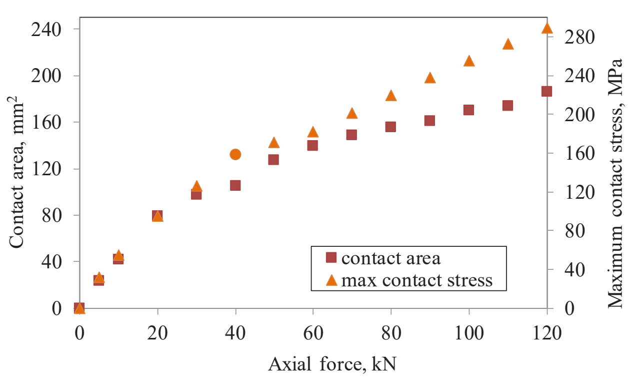


Fig. 9. Relationship between contact area and contact stress to axial force on 5 mm corrugated metal gaskets

From Fig. 9 shows that the contact stress and contact area of CMG thickness 5 mm is similar with CMG thickness 4 mm. However, the contact stress of CMG thickness 5 mm is higher than CMG thickness 4 mm and the contact area of CMG thickness 5 mm is lower than CMG thickness 4 mm.

5. 2. The optimum thickness of aluminum A1100 material to produce gasket

Fig. 10 shows the relationship between contact area and contact stress to axial force on 3 mm, 4 mm, and 5 mm.

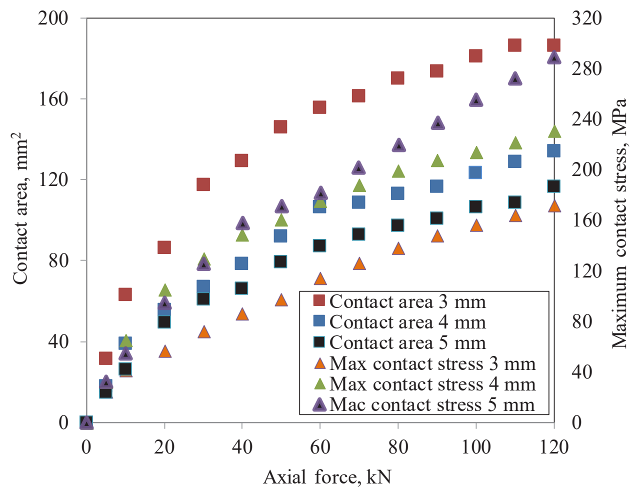


Fig. 10. Relationship between contact area and contact stress to axial force on a 3 mm, 4 mm, and 5 mm corrugated metal gaskets

From the Fig. 10 it can be concluded that the highest contact stress is CMG with a material thickness of 5 mm. However, CMG material with a thickness of 4 mm also has the characteristics of contact stress and contact area which are similar to those with a thickness of 5 mm.

The simulation results conclude that CMG with a material thickness of 5 mm is the optimum CMG design. As the gasket material thickness increases, so does the spring stiffness of the CMG. Increased spring stiffness increases the amount of contact stress. Similar to the lower thicknesses, the increase in the 5 mm gasket's axial force increases contact stress and contact width. This increase is also approaching the parabolic function with a positive slope.

5. 3. Leak performance of gasket measurement

Table 2 shows the leakage test results using a water pressure test on aluminum A1100 gaskets with a 3 mm, 4 mm, and 5 mm thickness. At an axial force of 40 kN, leakage still occurs in all gasket material thicknesses. No leak is evident at an axial force of 60 kN for water pressures of 5 MPa, 7.7 MPa, and 10 MPa, at all gasket material thicknesses. However, a leak still occurs at a water pressure of 12 MPa. These results are in accordance with previous studies [28], where at low fluid pressure there is no leak but at high fluid pressure a leak will occur.

At 80 kN axial force, there is no leakage for all gasket material thicknesses except for the water pressure of 12 MPa on the 3 mm gasket. At higher axial forces of 100 kN and 120 kN, there is no leakage on all thicknesses of gasket material at all water pressures. For a gasket with a thickness of 3 mm, at an axial force of 100 kN and a fluid pressure of 12 MPa, the axial force that occurs is 156.54 MPa and a contact area of 180.77 mm^2. In this condition, it is a state where there is no leakage. For a gasket with a thickness of 4 mm, at an axial force of 80 kN and a fluid pressure of 12 MPa, the axial force that occurs is 199.66 MPa and a contact area of 180.77 mm^2. In this condition, it is a state where there is no leakage. For a gasket with a thickness of 5 mm, at an axial force of 80 kN and a fluid pressure of 12 MPa, the axial force that occurs is 219.75 MPa and a contact area of 155.72 mm^2. In this condition, it is a state where there is no leakage.

Table 2

Leakage test result using water pressure test

Axial force (kN)	Water pressure (MPa)	Thickness		
		3 mm	4 mm	5 mm
40	5	Leak	Leak	Leak
	7.7	Leak	Leak	Leak
	10	Leak	Leak	Leak
	12	Leak	Leak	Leak
60	5	No leak	No leak	No leak
	7.7	No leak	No leak	No leak
	10	No leak	No leak	No leak
	12	Leak	Leak	Leak
80	5	No leak	No leak	No leak
	7.7	No leak	No leak	No leak
	10	No leak	No leak	No leak
	12	Leak	No leak	No leak
100	5	No leak	No leak	No leak
	7.7	No leak	No leak	No leak
	10	No leak	No leak	No leak
	12	No leak	No leak	No leak
120	5	No leak	No leak	No leak
	7.7	No leak	No leak	No leak
	10	No leak	No leak	No leak
	12	No leak	No leak	No leak

5. 4. The maximum pressure that gasket withstand the leakage

The water pressure in the water pressure test starts from 5 MPa, 7.7 MPa, 10 MPa and 12 MPa. Up to the highest pressure the gasket is still able to withstand leaks. The experimental results of 12 MPa pressure did not occur at axial forces starting at 100 kN for all thicknesses of gasket material. Gaskets with a thickness of 4 mm and 5 mm did not leak at a pressure of 12 MPa when the axial force is 80 kN. However, a gasket with a thickness of 3 mm leaks at a pressure of 12 MPa and a force of 80 kN. Therefore it is concluded that this gasket can withstand a maximum water pressure of 12 MPa with an axial force of 80 kN.

6. Discussion of development of aluminum A1100 as of corrugated metal gaskets

Compared to the leakage test results of the SUS304 gasket materials coated with Cu or Ni, the A1100 gaskets result are close. SUS304 gaskets coated with Cu [9] perform slightly better than aluminum A1100 gaskets. Meanwhile, the one coated with Ni [9] performs similarly to the A1100 gasket. Leakage did not occur in the CMG despite an axial force of 80 kN being relatively low when tightening using a torque wrench. There is no leakage even at an axial force of 60 kN, given that the maximum fluid pressure is 10 MPa (Table 3).

FEA simulation results using ANSYS software and leak test experiments generate validating results. The simulation results showed that the 5 mm thick CMG has the highest contact stress and lowest contact area, thus, the best-performing gasket, see Fig. 9. The performance was followed closely by the 4 mm CMG. However, the 3 mm thick CMG has relatively low contact stress and high contact area, see Fig. 9. The amount of contact stress is strongly influenced by CMG's spring stiffness. The contact area size is influenced by contact stress at certain CMG thicknesses [29]. The experimental results showed that CMGs with 4 mm and 5 mm thickness prevent leakage better than the 3 mm CMGs, see Table 2.

Table 3

Observation of leakage gasket SUS304 coated by Cu and Ni (adopted from [9])

Axial force (kN)	Water pressure test (MPa)	SUS304 gaskets	Cu Coated		Ni Coated	
40	5	No leak	No leak	No leak	No leak	No leak
	7.5	Leak	No leak	No leak	Leak	No leak
	10	Leak	Leak	Leak	Leak	Leak
	12	Leak	Leak	Leak	Leak	Leak
60	5	No leak	No leak	No leak	No leak	No leak
	7.5	No leak	No leak	No leak	No leak	No leak
	10	Leak	No leak	No leak	Leak	No leak
	12	Leak	Leak	No leak	Leak	Leak
80	5	No leak	No leak	No leak	No leak	No leak
	7.5	No leak	No leak	No leak	No leak	No leak
	10	No leak	No leak	No leak	No leak	No leak
	12	Leak	No leak	No leak	Leak	No leak
100	5	No leak	No leak	No leak	No leak	No leak
	7.5	No leak	No leak	No leak	No leak	No leak
	10	No leak	No leak	No leak	No leak	No leak
	12	No leak	No leak	No leak	No leak	No leak
120	5	No leak	No leak	No leak	No leak	No leak
	7.5	No leak	No leak	No leak	No leak	No leak
	10	No leak	No leak	No leak	No leak	No leak
	12	No leak	No leak	No leak	No leak	No leak

Based on the discussion above, the A1100 aluminum corrugated metal gasket design is suitable for gaskets in pipe flanges connection. The aluminum gasket does not leak during certain axial forces in the water pressure leak test. The leakage did not occur for gasket having thickness 3 mm, 4 mm, and 5 mm in axial force 100 kN and maximum water pressure 12 MPa, see Table 2. Manufacturing aluminum A1100 CMG is relatively easier than SUS304 gasket coated with copper. In addition, the costs of materials and manufacturing are also much lower than the SUS304 coated with Cu or Ni.

The limitation of this research is that the size of the gasket is 25A according to previous studies. This CMG adjusts the pipe dimensions, it means that for other pipe sizes optimization of CMG dimensions must be carried out. CMG dimensions not only depend on the thickness of the CMG material, but also include wave height, wave diameter, and flat portion length. Another limitation is the measurement of leaks which can be found by several methods. Leaks in this study were only seen visually in the presence of water droplets on white paper. Leaks can be seen using the helium leak test. This measurement is possible to see the helium leakage rate [4].

The disadvantage of this study is the thickness of the gasket material which depends on the presence in the market. The thickness of the gasket material can be found to be more optimal if the material can be made, for example through a casting process.

In the future, it will be possible to find the optimum dimensions for different pipe sizes in accordance with existing pipe standards in the industry. In addition, in the future it is also be possible to look for gasket materials that are softer but also corrosion resistant. These materials are nickel, brass, copper, or aluminum alloy.

7. Conclusions

1. Simulation analysis using ANSYS software generated results that support experimental results, where the amount of contact stress was 219.75 MPa and contact area was 155.72 mm^2 is a largest at a thickness of 5 mm. The best performance of CMG made of aluminum is the 5 mm thick gasket.

2. Based on the simulation and experimental analysis, the best thickness of CMG is 5 mm, because it has the highest contact stress.

3. CMG made from A1100 is suitable for use as a gasket to prevent leakage when used to connect pipe flanges.

4. The developed CMG withstands leakage at a maximum fluid pressure of 12 MPa.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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