Journal of Engineering Science and Technology
Vol. 15, No. 4 (2020) 2450 - 2463

THE PERFORMANCE OF NICKEL AND COPPER AS COATING MATERIALS FOR CORRUGATED METAL GASKETS

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Abstract

The corrugated metal gasket is currently still very much in development. This kind of gasket is essential to replace asbestos gasket, in which the production and usage are now prohibited. One of the development in corrugated metal gasket is the formation of three-layered gasket materials. However, the manufacture of this formation is difficult as the three materials that are formed together cannot strongly bond. The purpose of this research is to form a coating of copper and nickel for SUS304 corrugated metal gasket. The purpose of the coating is to have the outer layer, which is of copper or nickel, to infiltrate the rough surface of the pipe flange, resulted in a much higher contact width. The research also incorporate simulation and experimental work to determine the performance of the coated corrugated metal gasket. Results from the simulation and experiments indicate that the corrugated gasket's performance is improving, which was shown by the increase in contact width and the decrease of leakage from the water pressure test. The increase in contact width was 54% but the contact stress decrease 18% for copper coated 30 μm and contact width was increase 39% but the contact stress decrease 8% for nickel coated 30 μm. The leakage did not occur when axial force 80 kN for standard gasket, 40 kN for cupper coated, and 60 kN for nickel coated when the water pressure test 12 MPa.

Keywords: Coating, Corrugated metal gasket, Experimental, Leakage, Simulation.

1. Introduction

Corrugated metal gasket is currently being developed to replace asbestos gasket. Metal gasket is most suitable for pipe joints with a stream of corrosive and high temperature chemicals. The metal in this case is corrosion-resistance steel. The metal gasket is made corrugated to make it stick tightly to the flange. The corrugated part of the gasket consists of flats and rounds areas. The flat areas give a spring effect and the rounded areas serve to generate local contact stress. The rounded part of the gasket would form a sealing liner at the flange, which would then prevent leakages [1].

Corrugated metal gasket sized according to 25A standard has been developed by Nurhadiyanto et al. [2] using finite element method. An optimum design were tested using helium test. The influence of flange surface roughness towards leakages was researched by Haruyama et al. [3]. The surface roughness of the pipe flange greatly affects the leakage. The aforementioned research, however, still have their weaknesses as they required high tightening force. It was also observed that for a flange with a high surface roughness (above 3.5μm), helium leakage was still occurred. To overcome the surface roughness problems while maintaining spring stiffness of the gasket. Haruyama et al. [4] and Karohika et al. [5] have modified the standard gasket by layering the outer part with a softer material. In addition to the primary metal gasket material, the outer part was coated with a layer of copper. However, it was quite difficult to manufacture the gasket with three layers of materials because copper cannot bond well with steel.

Nurhadiyanto et al. [6] developed an SUS304 corrugated metal gasket coated with copper, which is a softer material, utilizing finite elements method. The result showed an increase of contact width and a slight decrease of contact stress. The increase in contact width will lower the gasket leakage rate. However, this theory of leakage test has not been proven by experimental methods. Further research needs to be carried out to find other material which is softer than SUS304 but has the characteristics that can withstand high temperature condition and is corrosion resistant. Among such materials are copper and nickel. Huang et al. [7] investigated the electrochemical corrosion of Cr-C-coated steel sample with Ni and Cu. Electrochemical corrosion resistance was detected at 0 V. Ming et al. [8] studied corrosion behaviours of electroless Ni-Cu-O/n-TiN composite coating. They are founded that the Cu content increased, the corrosion current density of coating decreased. Based from both article, the corrosion of material decrease by copper or nickel coated.

Margen et al. [9] conducted an AISI304 stainless steel coating experiment with nickel-coated copper by considering a time variable and a fixed electric current parameter. Copper coating effectively occurred on the stainless-steel material, with the best results obtained at a current of 1.5 A and time of 180 s. The thickness of the copper attached to the stainless steel was suggested as 26.50 μm.

In order to achieve those characteristics mentioned above, corrugated metal gaskets coated with copper or nickel of certain thickness were developed. The analysis was carried out using finite element method simulation and the leakage test were carried out using water pressure test. Gasket material, the SUS304, were formed into corrugated shape and subsequently coated with copper and nickel, respectively. Coating with a softer material was intended to make the outermost material bonds perfectly and infiltrate the rough surface of the flange, thus preventing leakage.

The purpose of this research are (1) forming the flat SUS304 gasket into corrugated shape (2) to perform coating on the corrugated metal gasket with copper and nickel layers, respectively, of certain thicknesses (3) to define the contact stress and contact width of the coated corrugated metal gasket using finite element method simulation (4) to test for leakages using water pressure test for each coating material thickness.

2. Material and Method

The base material of the gasket was SUS304 metal. This material has a good chemical resistance and can withstand high temperatures. The mechanical properties of SUS304, copper, and nickel according to [10, 11] shown in Table 1. Based on these mechanical properties, it can be inferred that copper and nickel are both softer than steel. The characteristics comparison of copper, nickel and SUS304 is depicted in Fig. 1.

Table 1. The properties of SUS304, copper, and nickel.

Properties	Value		
	SUS304	Copper	Nickel
Yield stress	398,83 MPa	195 MPa	210 MPa
Elasticity modulus	210 GPa	115 GPa	170 GPa
Tangential modulus	1900,53 MPa	1150 MPa	1200 MPa

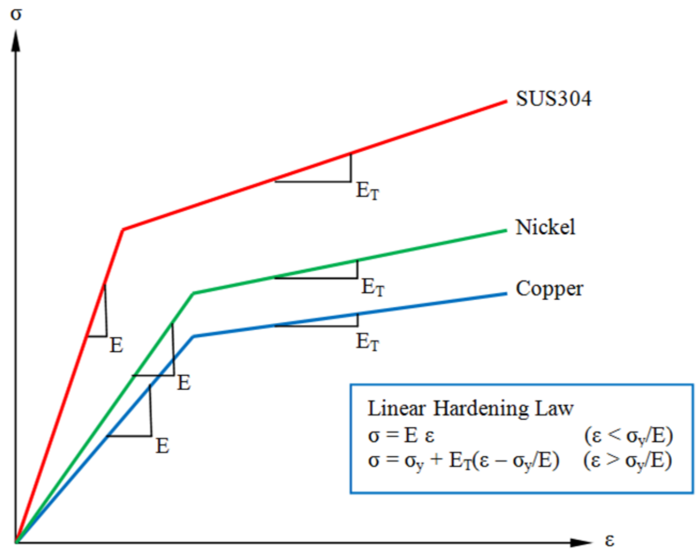


Fig. 1. Linear strain hardening model for SUS304, copper, and nickel material.

The formed gaskets were corrugated disc gaskets consist of 2 rounded part on the upper and bottom sides. The gasket was formerly a flat disc and was cold formed using a set of dies loaded with certain loads. The outer and inner diameter of the gasket were cut based on JISB2404 standard dimensions [12]. The dies dimensions were obtained from the optimum dimension resulted from finite element methods and Taguchi methods, completely in literature [2]. The flange material used in this research was also from SUS304 metal. The flanges were general-purposed flanges which were based on JISB2220 standard [13] with 10 K pressure. According to this standard, the flanges size were 25A diameter.

Simulation analysis were carried out to define the contact stress and contact width. These two properties were used to determine the optimum gasket design and to predict leakages rate. The analysis was done using MSC MARC software with a 2-dimensional axisymmetric model, using quadrilateral meshing for gasket material and coating material. First, the gasket and flange were modelled as cut sections using Solidworks 3D modeler software. The meshing process was performed using Hypermesh software. The meshing of gasket and flange was using quadrilateral elements. Finally, the finite element methods simulation was carried out using MSC MARC. The gasket material layers were copper-base material-copper (Cu-SUS304-Cu) or nickel-base material-nickel (Ni-SUS304-Ni). The thickness of copper or nickel coatings was varied, that were 20 µm and 30 µm. These thicknesses were chosen based on the initial research that the maximum contact width and the average contact stress still above 800 MPa when the thickness of copper or nickel in between 20 µm and 30 µm. The simulated process was the tightening of the gasket by the flanges, as depicted in Fig. 2. Gasket material and flange are assumed as deformable bodies. The boundary condition: bottom flange move up only and upper flange move down only. The inner gasket could not move in horizontal direction, but the outer gasket possible move in horizontal direction. After the FEM analysis was completed, data of axial force, contact stress, and contact width were obtained. These data were then converted to Microsoft Excel file.

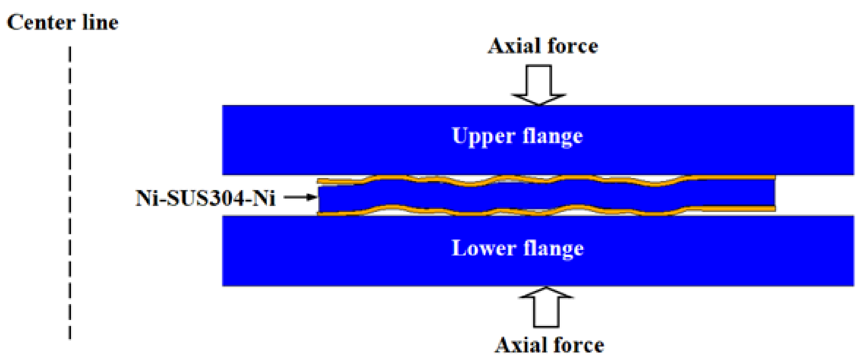


Fig. 2. Simulation of the tightening process.

The gasket base material, the SUS304, was in the form of a flat ring. The dimension of the base material was 1.5 mm thick, an outer diameter of 7.5 mm and an inner diameter of 20 mm. Gasket material before being cold formed is shown in Fig. 3. This material was then formed into corrugated shapes. The gasket after being formed is shown in Fig. 4.

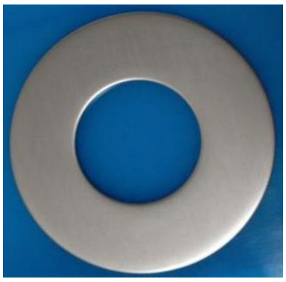


Fig. 3. Gasket base material.

Fig. 4. Corrugated-formed metal gasket.

The forming of corrugated gasket was cold formed in a press machine with a compressive force of 1100 kN. First, the lower die was placed on the base of the machine. The gasket base material was placed on top of the lower die, afterwards. Then, the upper die was fixed on top of the gasket base material. The final step was to apply a load of 1100 kN to the upper die [14, 15]. The forming process were performed in 30 seconds and in three iterations to anticipate for the spring back effect of the metal gasket. The applied force during the forming process is depicted in Fig. 5.

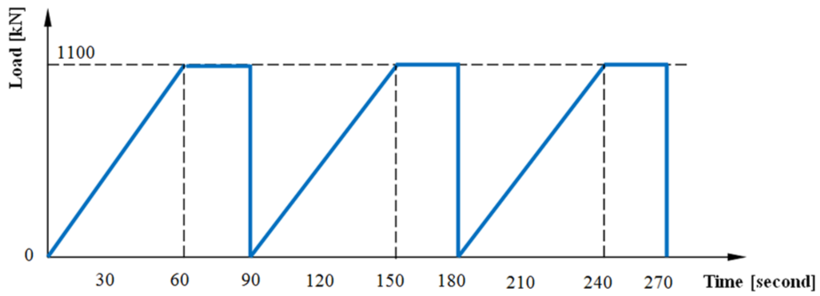
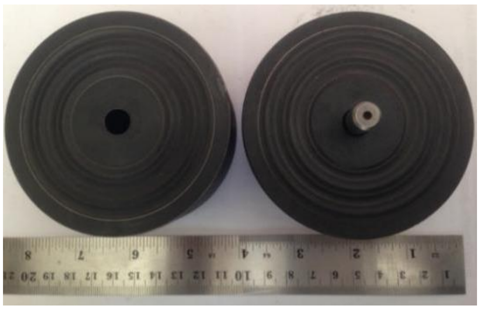


Fig. 5. Gasket tightening force.

The material of the die was Bohler® K105 stainless steel. The Bohler® K105 has a hardness of 15.3 HRC, which was not hard enough to form the corrugation of the gasket material. Therefore, the dies material then went into further processing, which was hardening. The dies material was heated to 900°C. At this temperature, the dies will be burning hot. Subsequently, the dies were suddenly immersed in oil and maintained until it cooled off. The measured hardness of the die after quenching was 54.1 HRC. Figure 6 shows the die before and after the hardening process. The dimension of dies can be seen in previous research by Nurhadiyanto et al. [2], especially for plastic design mode.

(a) The die before hardening process



(b) The dies after hardening process

Fig. 6. Photos of the dies before and after hardening process.

After the corrugated metal gasket was formed, the next step was coating it with layers of copper and nickel, separately. The thickness of nickel or copper layer was varied, that are 20 µm and 30 µm. The coating process using electroplating is not to be discussed in this article. The coating result for copper and nickel-coated was good. There no crack before and after use. Figure 7 shows the gaskets after coating process.

(a) Copper-coated gasket.

(b) Nickel-coated gasket.

Fig. 7. The Gaskets after coating process.

The test scheme for leakage was water pressure test. The instruments were set in accordance with JIB2490 standard. The water pressure was varied to 5 MPa, 7.5 MPa, 10 MPa, and 12 MPa. Leakage data were taken every 600 seconds. The measured leakage was the occurrence of fluids drip between the gasket and the flange, and pressure loss observed at the pressure gauge. Figure 8 depicts the schematics of water pressure test.

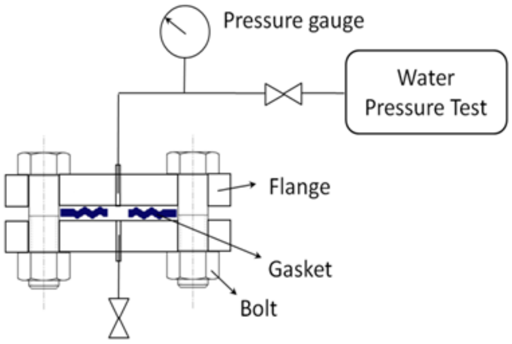


Fig. 8. Leakage test using water pressure test.

The gasket performance was evaluated by the correlation between axial force and water leakage. Axial force is generated by the tightening force of the flange on the bolts. However, the prediction of accurate axial force cannot be obtained, due to the variation in coefficient of friction in each of the bolts and nuts of the flange. In this research, the axial force was measured using digital torque wrench. Therefore, the axial force data can be obtained during tightening of the bolts.

Prior to be used for tightening, the digital torque wrench was calibrated. The varied axial forces being measured were 10, 15, 20, 25, and 30 kN, for each bolt. The axial force of each bolt was monitored in order to adjust the appointed axial force error to be below 3%. Four bolts were used to tighten the flanges; therefore, the axial forces were 40, 60, 80, 100, and 120 kN, respectively.

Figure 9 shows the setting of water pressure test to observe water leakages. The experiment was carried out on a lathe machine in the Fitting and Machining Workshop of Mechanical Engineering Education, Engineering Faculty, Universitas Negeri Yogyakarta. To clamp the flange, the lathe chuck was used to support the tightening of the bolts.

Fig. 9. Experiment setting of the water pressure test.

Figure 10 shows the tightening process and leakage observation using water pressure test. As mentioned above, the axial force was measured using the digital readout of the torque wrench, as shown in Fig. 10(a). The researcher calibrated the digital torque wrench, which in turn derived the axial force from the torque. Figure 10(b) shows the setting of water leakage test. This device provides pressurized water to the desired pressure after being pumped. Figure 11 shows the test to determine whether there was any leakage in the tightening process. If there was a drip of leakage, it can be easily observed against a white sheet of paper.

(a) Tightening force measurement.

(b) pressure measurement.

Fig. 10. Tightening force and pressure measurement.

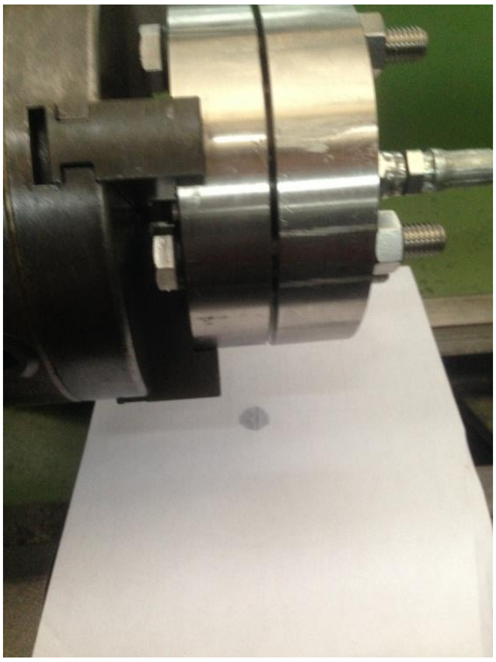


Fig. 11. Leakage observation.

3. Results and discussion

The simulation resulted in contact width and contact stress data at specific axial forces. This research has found the contact width and contact stress of corrugated metal gasket coated with copper and nickel. Each of the coating material has a thickness of 20 µm and 30 µm. The result shows that the characteristics of copper and nickel as coating material is similar. Figure 12 shows the contact stress and contact width values for copper coating of 20 µm and 30 µm thicknesses at the graduation of axial forces. Figure 13 shows the contact stress and contact width for nickel coating of 20 µm and 30 µm thicknesses at the graduation of axial forces.

Figure 12 shows that, as the axial force increases, the contact stress also increases. The contact stress increase is at maximum at 50 kN axial force. Above this point, the contact stress decreases gradually. The contact stress is approximately constant when the axial force reaches 80 kN to 120 kN. The change in contact stress applies to the three gaskets, namely SUS304 gasket, copper-coated gasket with 20 µm in thickness, and copper-coated gasket with 30 µm in thickness. The similar results were obtained for nickel-coated gasket at 20 µm and 30 µm in thickness. There is a small difference in the value of contact stress in SUS304 gasket, 20 µm copper-coated gasket, and 30 µm copper-coated gasket. The SUS304 gasket has a higher contact stress compared to the 20 µm and 30m copper-coated gaskets. The 30 µm coated gasket has the lowest contact stress of all.

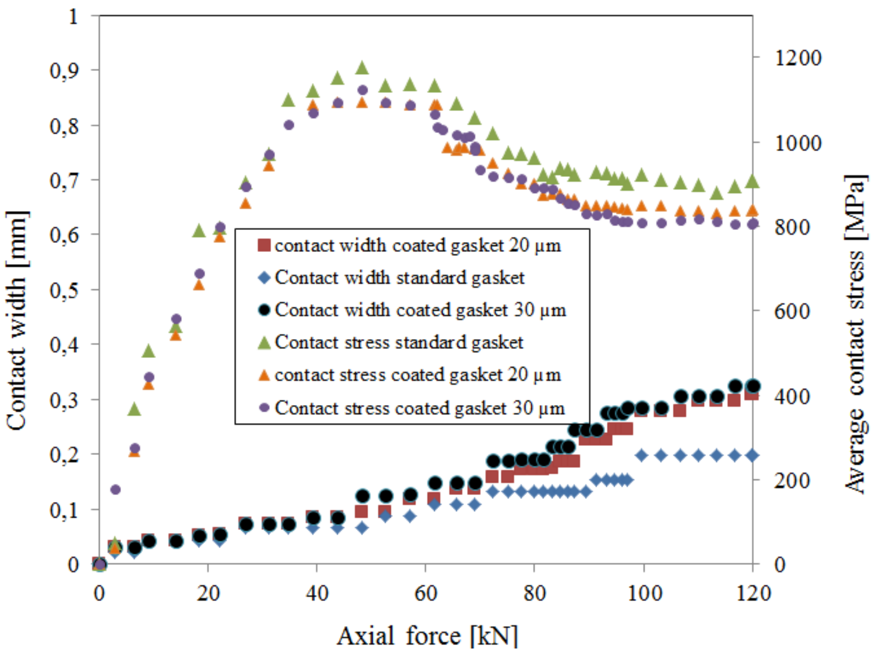


Fig. 12. The average contact stress and contact width of copper-coated gasket.

Figure 12 also pinpoint the gradual increase of contact width along with the increase of the axial force. The contact width increases slightly for axial force at and above 80 kN. The change in contact width applies to the three gaskets. There was also a small difference in the value of contact width of the three gaskets. The 30 µm copper-coated gasket has a higher contact width compared to the 20 µm copper-coated gasket and the SUS304 gasket. The SUS304 gasket has the lowest contact width compared to the other two. Similar with Fig. 12, Fig. 13 shows the average contact stress and contact width. In Fig. 13, contact width increase gradually. The average contact width of copper-coated gasket is wider than contact width of nickel-coated gasket due to copper material fills more flange surface roughness than nickel material. But the average contact stress of copper-coated gasket less than nickel-coated gasket.

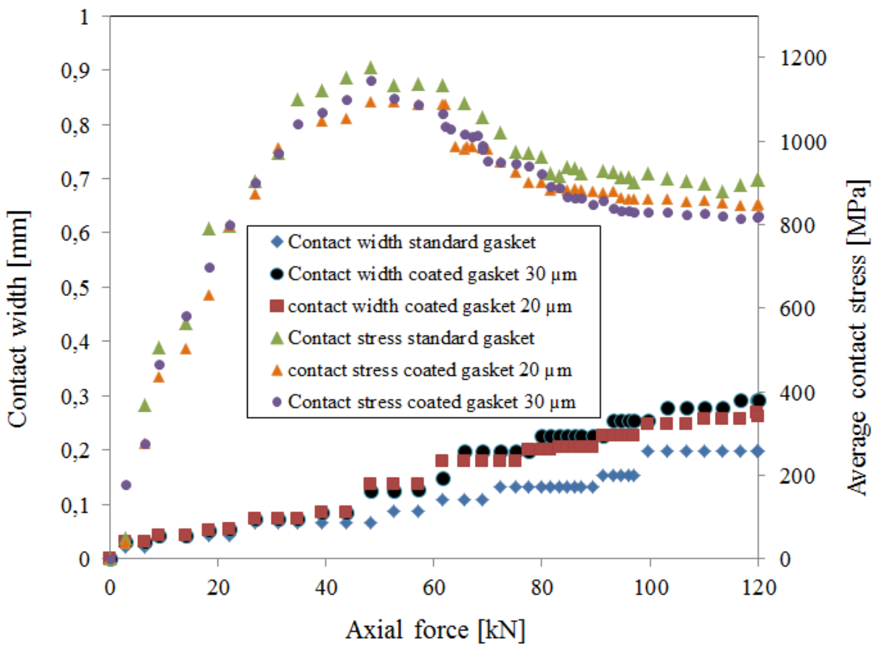


Fig. 13. The average contact stress and contact width of nickel-coated gasket.

When the axial force is between 0-40 kN, the contact stress increases because the gasket is still in elastic condition. The gasket in plastic condition is reduced after the axial force 50 kN, so the contact stress is reduced to the minimum condition. The gasket in plastic condition is identical to the description above, so the contact stress stabilizes above 80 kN of axial force.

Based on the discussion above, it can be concluded that the use of a softer material for coating resulted in an increase in contact width. Inversely, the contact stress decreases. Increasing the coating layer thickness also increases the contact width, at the expense of a decrease in contact stress. The average surface roughness of the flange is 2.5µm, therefore the coating layer thickness of 20 µm and 30 µm were chosen. Best case scenario can be done using experiments.

Regarding the nickel coating, it is mentioned above that there are similarities between copper and nickel coatings. Simulation analysis shows that the increase in contact width of the copper coating is higher than the nickel coating of the same coating thickness. The decrease of contact stress on the copper coating is higher compared to nickel coating, also at the same coating thickness.

Table 2 presents the result of gasket leakage test using water pressure test for SUS304 gasket, copper-coated gasket and nickel-coated gasket. This experiment results compares the leakage test for the SUS304 gasket, the 20 µm copper-coated gasket, the 30 µm copper-coated gasket, the 20 µm nickel-coated gasket, and the 30 µm nickel-coated gasket. Water pressure was maintained at 10 MPa, and the data were recorded for 600 seconds long. Axial forces were set at 40 kN, 60 kN, 80 kN, 100 kN and 120 kN, which were exerted by the tightening of the bolts. Digital torque wrench displays the torque imposed on the bolts and using mathematical formulae the axial forces can be calculated from the torque data. The axial force is fourfold because there were 4 tightened bolts.

Table 2 also shows that leakage occurred on SUS304 gasket at 80 kN axial force and 12 MPa water pressure. However, at 10 MPa water pressure, there was no leakage. For an axial force of 100 kN and above, there was no leakage on the gasket. Copper-coated gasket underwent a change in its performance, in which the leakage occurrence stopped at 80 kN axial force for the coating thickness of 20 µm. The leakage for 30 µm copper-coated gasket stopped at 60 kN axial force. Thus, the 30 µm coated gasket has the best performance when compared to the 20 µm coated gasket and the gasket without coating. The gasket coated with 20 µm copper coating has a better performance than the gasket without coating.

The change in performance for nickel-coated gasket is shown by the fact that the leakage stopped at 100 kN axial force for the 20 µm coating thickness. The leakage in gasket with 30 µm nickel coating stopped at 80 kN axial force. Thus, the gasket with 30 µm coating has the best performance compared to the gasket with 20 µm coating and the gasket without coating. The 20 µm coating gasket has the same performance to the gasket without coating.

Copper-coated gasket has a better performance than nickel-coated gasket at the same coating thickness. The 20 µm copper-coated gasket performed better than the 20 µm nickel-coated gasket. Likewise, the 30 µm copper-coated gasket performed better than the 30 µm nickel–coated gasket. As a softer material, copper infiltrate the flanges' rough surface better than nickel, thus prevents leakage. This finding confirmed the simulation result. Copper also has a higher contact width value compared to nickel.

Even though nickel is inferior to copper in preventing leakage, nickel does improve the gasket performance when coated on SUS304 gasket. This can be seen from the 30 µm nickel coating, in which leakage did not occur at 80 kN axial force and 12 MPa water pressure while on the SUS304 gasket, leakage still occur at the same force and pressure.

The experimental results have confirmed the result from the simulation. copper-coated and nickel-coated gasket have a higher contact width value compared to SUS304 gasket. At the same layer thickness, copper coating performs better than nickel coating. The simulation also gave the same result, which is for the same coating thickness, contact width of the copper coating is higher than nickel coating. The increase in contact width helps prevent leakages when the contact stress value is sufficient to form a seal lining. The average contact stress value should be above 800 MPa [16].

Table 2. Observations of leakage using water pressure test.

Axial force (kN)	Water pressure test (MPa)	SUS304 gasket	Cu Coated		Ni Coated	
			20 μm	30 μm	20 μm	30 μm
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

4. Conclusion

On the basis of the simulation and leakage test experiments results, it can be can concluded that

- Cold forming process of flat shape material to be corrugated metal gaskets has been successful.
- Coating result of both copper and nickel was good. There is no crack before and after used.
- Contact width of the copper-coated gasket is higher than the nickel-coated gasket. Nickel-coated gasket has a higher contact width value compared to the SUS304 gasket.
- Leakage performance on copper-coated gasket is better than the nickel-coated gasket. Whereas nickel-coated gasket has better performance than SUS304 gasket. The experimental findings from the water pressure test verified the simulation results. On the coating of copper and nickel, the thickness of 30 μm has a better leakage performance than the thickness of 20 μm.

Recommendations

To test in real conditions, it is necessary to research leakage tests at high temperature.

Acknowledgements

This project was supported by Direktorat Riset dan Pengabdian Masyarakat, Direktorat Jenderal Penguatan dan Pengembangan, Kementerian Riset, Teknologi dan Pendidikan Tinggi, Skema Penelitian Terapan Unggulan Perguruan Tinggi, sesuai Kontrak Penelitian Anggaran Tahun 2019 Nomor 080/SP2H/LT/DRPM/2019.

Nomenclatures

E	Modulus elasticity
E_T	Linear work-hardening
HRC	Rockwell hardness scale
SUS	Japanese name for austenite stainless steel

Greek Symbols

σ	Stress
ε	Strain

Abbreviations

FEM	Finite Element Method
JIS	Japanese Industrial Standards

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