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An Approach to Optimize the Corrugated Metal Gasket Design Using Taguchi Method

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***Abstract*— Since Asbestos has been banned, the research and development of new gasket materials and designs have continued. One of the materials that are closest to the nature of asbestos is metal. Metal gaskets have been used extensively as static insulation in many industries because they have high temperature and chemical resistance, can withstand pressure, be recycled, and reliability in critical situations. Types of metal gaskets can be distinguished based on their shape. The focus of this research is the corrugated type gasket. Based on previous research, it has been found that important parameters of metal gasket performance are contact width and contact stress. Research developed so far is that the design of corrugated metal gaskets is divided into two types based only on the contact width of the plastic conditions without considering the magnitude of the contact stress and vice versa. In this study, we propose a new approach with contact width and contact stress calculated together as evaluation criteria to optimize corrugated metal gaskets' design. The Taguchi method is used as an optimization design method and a finite element software to obtain result data. This study aimed to obtain an optimal gasket design by utilizing this new approach by using the Taguchi method as an experimental design and simulation method to obtain the result data. This will result in a new design of corrugated metal gasket type which can prevent better leakage performance.**

***Keywords*— optimization; contact width; contact stress; design; corrugated; gasket.**

I. INTRODUCTION

Tourism has contributed significantly to the economy on the island of Bali. Discussing tourism cannot also be separated with hotels and piping systems. The piping system requires the pipe itself connected to the flange and gasket. A good piping system such as Boilers where the hot fluid is flowing is very important not to experience leakage. Gaskets used so far are made from asbestos. The main problem is that gaskets made from Asbestos are very dangerous for health, so their use is prohibited and is something urgent to get a replacement [1], [2]. One of the materials approaching the performance of asbestos gaskets is metal gaskets. The development of gaskets is currently focused on discovering new materials to replace asbestos and optimizing gasket designs in their shape and dimensions.

Optimization of metal gasket design by evaluating the contact area and contact width criteria separately by using finite element software and the Taguchi method has resulted in a new design of corrugated metal gaskets (CMG) [3]. In subsequent studies using the contact width evaluation criteria and considering the forming process and the gasket's plastic conditions succeeded in getting the optimum new shape [4]–[6]. The effect of surface roughness on the gaskets' design performance was also investigated, which found the surface roughness of the flange plays an important role where the performance of the gasket decreases with an increasing roughness value of the flange surface [7], [8]. The next gasket development is to improve its performance by layered [9], [10], and the optimum design is also obtained where there is no leakage at the low tightening force of 40 kN [11]. This layered model's weakness is when mounting on the flange because the surface with the core material is not bound so it is easy to move; therefore, it affects the performance of the gasket. Research on CMG also found that the use of closed dies produces better products than open dies [12], and the coefficient of friction also affects product quality [13]. The sealing performance of the CMG shows good performance for all types of flanges [14]. Finite element software as a tool for predicting results accurately is increasingly widespread and important to be used in engineering [15]–[19]. Another metal gasket study was the copper coating method, which improved gasket performance without leaking at 60 kN [20], and the flange surface roughness degree after being used [21]. In previous studies, the evaluation criteria used as the basis for optimization are the tightening force's contact width; although the plastic conditions of the contact width have been calculated, the magnitude of the contact stress is not directly included in the determination of design optimization.

In this study, we propose a new approach with contact width and contact stress calculated together as evaluation criteria to optimize corrugated metal gaskets' design. The Taguchi method is used as an optimization design method and a finite element software as a tool for obtaining result data. This study aimed to obtain an optimal gasket design by utilizing this new approach by using the Taguchi method as an experimental design and simulation method to obtain the result data.

II. Material and Method

In this study, the gaskets used were corrugated gasket circumference beads. The shape of the gasket consists of a flat part and a convex section. The convex section provides high local contact stress when in contact with the flange to prevent leakage at low tightening forces. The flat section functions as a spring, which keeps the convex part in touch when the flange connection is relaxed so that the convex section can function optimally. The gasket material used is SUS304 because of its corrosion-resistant ability and resistance to working in high temperatures. The mechanical properties of the sus304 material are shown in table 1.

TABLE I
MECHANICAL PROPERTIES OF SUS304

Properties	Value
Yield stress (Mpa)	398,83
Modulus tangen (Mpa)	1900,53
Modulus elastisitas (E) GPa	210
Poisson ratio (v)	0.3

Gasket design is modeled in 2 dimensions and axisymmetric analysis, as shown in Fig.1. Gaskets are modeled with deformable bodies, fulfill linear strain hardening law (fig.2), while dies and flanges are modeled with rigid bodies. Dies for forming processes used are closed dies type because they give better results compared to open dies. The type of flange used is the type of flat face type as shown in Fig.3. The simulation method consists of two processes namely the forming process (fig.4) and the tightening process (fig.5). The forming process is modelled because gaskets are formed with cold forming press molds. The tightening process is the process of tightening by the flange against the formed gasket. Modelling, meshing, and running a simulation process using MCS software. Marc. In forming the initial flat plate, a moving die is pressed to form a corrugated model gasket. Then the flange moves to press the gasket that has been formed to get the output data in the form of tightening force, contact status, contact width, and contact stress. This output data is then processed in the Microsoft Excel file to produce a relationship between tightening force and evaluation criteria.

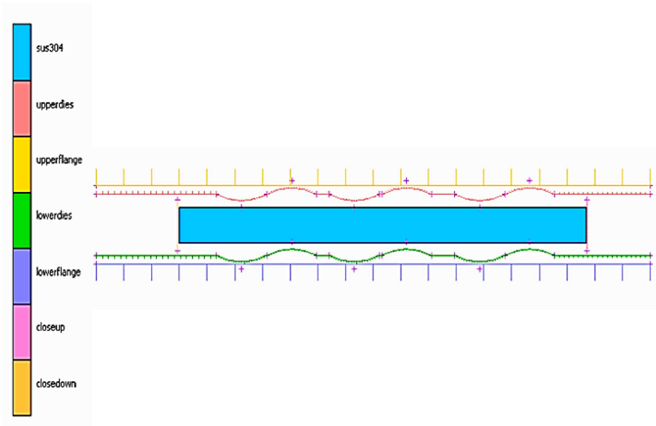

Fig. 1 Gasket simulation model in 2 dimension

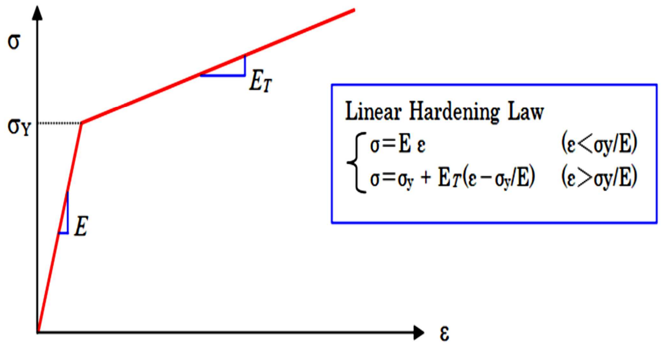

Fig. 2 Linear strain hardening model for SUS304

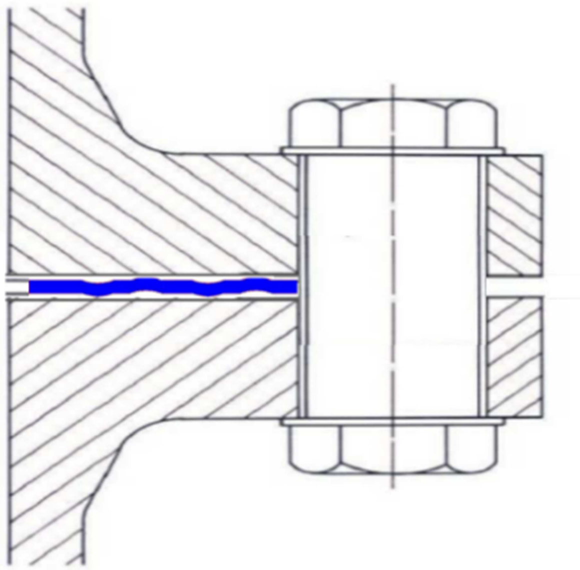

Fig. 3 The flat face flange type

As an evaluation criterion for an optimal design uses 2 criteria, namely: criterion 1, the slope between tightening force to contact width in plastic conditions (*cw*) and criterion 2, the slope between tightening force to contact width in plastic conditions, and contact stress at the same time (*F/ l*). Criterion 2 is a new approach to obtain an optimal design and criterion 1 is a previous research model as a comparison. The formula derivation of criterion 2 is as follows:

$$F = \sigma_{avg}.A_{plastis} \quad (1)$$

$$F = \sigma_{avg}.(cw.l)_{plastis} \quad (2)$$

$$F/l = \sigma_{avg}.(cw)_{plastis} \quad (3)$$

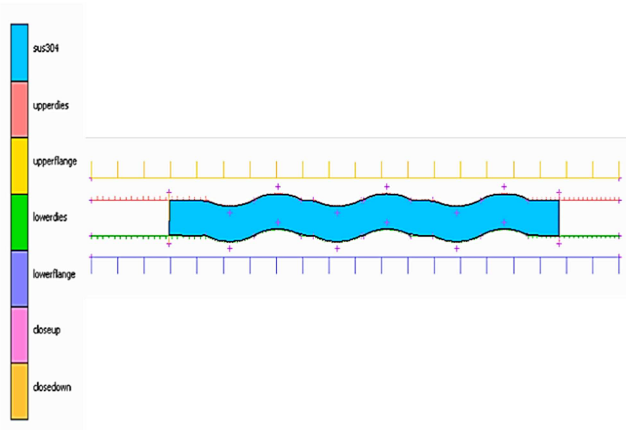

Fig. 4 Forming process simulation

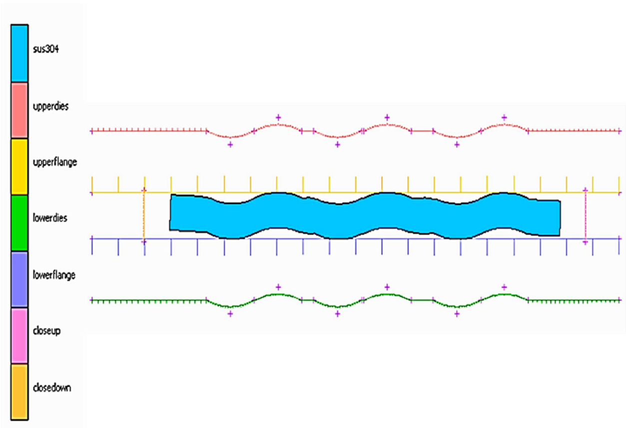

Fig. 5 Tightening process simulation

TABLE II
THE LEVEL OF DESIGN PARAMETER ON CORRUGATED METAL GASKET

No.	Design Parameter	Level 1	Level 2	Level 3
1	Total length (L) [mm]	19.5	19.0	-
2	Pitch 1 (P1) [mm]	2.5	3.0	3.5
3	Pitch 2 (P2) [mm]	2.5	3.0	3.5
4	Pitch 3 (P3) [mm]	2.5	3.0	3.5
5	Thickness (t) [mm]	1.4	1.5	1.6
6	Radius (R) [mm]	2.0	2.5	3.0
7	Height (h) [mm]	0.25	0.30	0.35
8	Overhang (OH) [mm]	2.0	2.5	3.0

For the optimization method using the Taguchi method where eight design parameters have been determined and three levels of variation as shown in table 2. Design parameters are the length of the gasket (L), pitch 1 (P1), pitch 2 (P2), pitch 3 (P3), the thickness of gasket (t), the radius of convex (R), the height of convex (h) and overhang (OH). There is a modification in the overhang section which is in the shape of convex compared to previous research in the shape of flat. In the Taguchi method, the signal to noise ratio (S/ N ratio) is used as a performance measure of quality characteristics. In this study, the S/ N ratio of the larger the better was chosen as a measure of gasket performance.

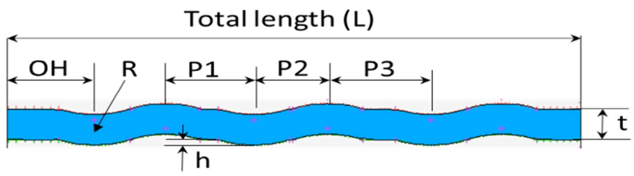

Fig. 6 Gasket cross-section and design parameter

This means that a gasket has good quality if it has a higher slope value. S/N ratio for larger the better:

$$S/N_L = -10\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (4)$$

Where, n is the number of data points, y_i $(i = 1, 2, \ldots n)$ stands for individual output values.

An orthogonal array is a factor and level matrix arranged in such a way that the influence of a factor and level does not blend with other factors and levels. Matrix elements are arranged according to rows and columns. The row is the state of a factor while the column is a factor that can be changed in experiments. In this study, L18 was used as an experimental design consisting of 8 factors and 3 levels as shown in table 3.

TABLE III
L18 ORTHOGONAL ARRAY

Run	L	P1	P2	P3	t	R	h	OH
1	19.5	2.5	2.5	2.5	1.4	2.0	0.25	2.0
2	19.5	2.5	3.0	3.0	1.5	2.5	0.30	2.5
3	19.5	2.5	3.5	3.5	1.6	3.0	0.35	3.0
4	19.5	3.0	2.5	2.5	1.5	2.5	0.35	3.0
5	19.5	3.0	3.0	3.0	1.6	3.0	0.25	2.0
6	19.5	3.0	3.5	3.5	1.4	2.0	0.30	2.5
7	19.5	3.5	2.5	3.0	1.4	3.0	0.30	3.0
8	19.5	3.5	3.0	3.5	1.5	2.0	0.35	2.0
9	19.5	3.5	3.5	2.5	1.6	2.5	0.25	2.5
10	19.0	2.5	2.5	3.5	1.6	2.5	0.30	2.0
11	19.0	2.5	3.0	2.5	1.4	3.0	0.35	2.5
12	19.0	2.5	3.5	3.0	1.5	2.0	0.25	3.0
13	19.0	3.0	2.5	3.0	1.6	2.0	0.35	2.5
14	19.0	3.0	3.0	3.5	1.4	2.5	0.25	3.0
15	19.0	3.0	3.5	2.5	1.5	3.0	0.30	2.0
16	19.0	3.5	2.5	3.5	1.5	3.0	0.25	2.5
17	19.0	3.5	3.0	2.5	1.6	2.0	0.30	3.0
18	19.0	3.5	3.5	3.0	1.4	2.5	0.35	2.0

III. Result and Discussion

The contact width is measured by the number of gasket elements that have contact with the flange. Determination of contact width is done by considering contact stress by removing contact stress values below the nominal stress of 398.83 MPa. Sealing lines will form on contact widths that have plastic contact stress conditions (Fig. 6).

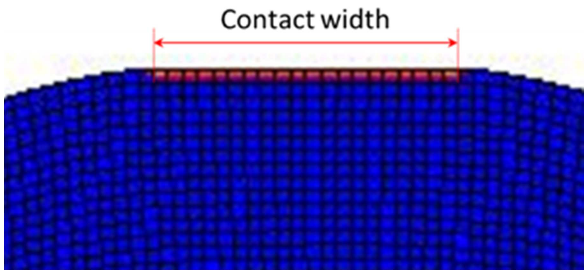

Fig. 7 Contact width status

Based on simulation results and processed in Microsoft Excel, contact width, contact stress, and tightening force data are obtained. Then the slope between the contact width against the tightening force for criterion 1 and the slope force per length unit for the tightening force for criterion 2 obtained. Fig. 7 shows one of the relationships between contact width and axial force for criteria 1 and fig. 8 shows the relationship between for per length unit and axial force for criteria 2.

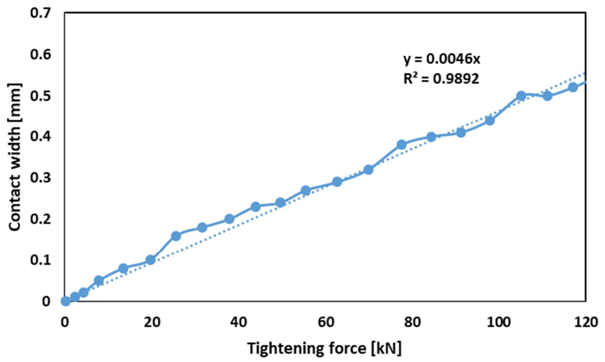

Fig. 8 Slope for criteria 1

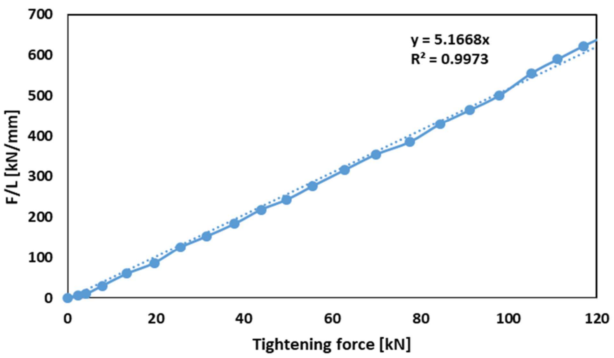

Fig. 9 Slope for criteria 2

The 18 simulation results are shown in Table 4. Minitab 19 statistical software used to analyze the Taguchi design as well as the Mean plot and plot S / N ratio of each factor.

TABLE IV
The Simulation Result for Each Criterion

Run	Criteria	
	1	2
1	0.0043	5.3047
2	0.0042	5.0593
3	0.0043	4.9066
4	0.0049	5.0232
5	0.0046	5.1403
6	0.0044	5.2954
7	0.0048	5.0498
8	0.004	4.7989
9	0.0043	4.9708
10	0.0042	5.1102
11	0.0043	4.8058
12	0.0042	3.3477
13	0.0039	4.6559
14	0.0047	5.1371
15	0.0044	4.9936
16	0.0047	5.0858
17	0.004	4.6728
18	0.0044	4.7662

TABLE V
Response Table for the Signal to Noise Ratio of Criterion 1

Larger is better

Level	Length	Pitch 1	Pitch 2	Pitch 3	Thickness	Radius	Height	Over hang
1	-47.10	-47.43	-47.03	-47.21	-46.98	-47.68	-47.01	-47.31
2	-47.32	-46.99	-47.35	-47.25	-47.15	-47.05	-47.28	-47.34
3		-47.22	-47.26	-47.18	-47.51	-46.91	-47.35	-46.99
Delta	0.22	0.44	0.32	0.07	0.54	0.77	0.34	0.35
Rank	7	3	6	8	2	1	5	4

Table 5 shows the sequence of factors that have the greatest to smallest influence on slope contact width and tightness force, namely radius, thickness, Pitch 1, Overhang, height, Pitch 2, length, and Pitch 3. Based on the results we can know that the radius and thickness factors have an influence significant enough to design criterion 1.

In addition to the output in the form of text, the results of the analysis are made graphically as shown in Fig. 9. Based on the S/ N ratio graph, it is seen that the tilt of the radius and thickness factors is very large. This shows that the influence of the two factors is very large. On the contrary, the slope of the length and pitch factor 3 is very small, which shows the effect is very small too. Based on Fig. 9 we also get the optimal design for criterion 1 by selecting the maximum level value for each factor. The optimal design of gaskets based on criteria 1 is shown in table 6.

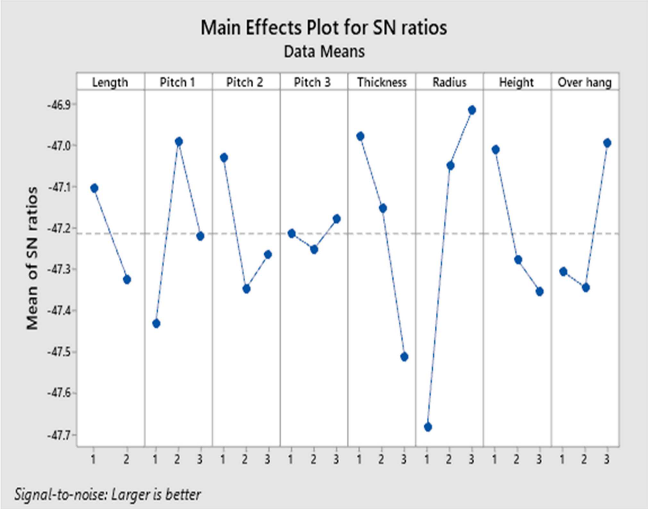

Fig. 10 Plot S/N ratio for criterion 1

TABLE VI
THE OPTIMUM DESIGN FOR CRITERION 1

No.	Design Parameter	Value
1	Total length (L) [mm]	19.5
2	Pitch 1 (P1) [mm]	3.0
3	Pitch 2 (P2) [mm]	2.5
4	Pitch 3 (P3) [mm]	3.5
5	Thickness (t) [mm]	1.4
6	Radius (R) [mm]	3.0
7	Height (h) [mm]	0.25
8	Overhang (OH) [mm]	3.0

TABLE VII
RESPONSE TABLE FOR THE SIGNAL TO NOISE RATIO OF CRITERION 2

Larger is better

Level	Length	Pitch 1	Pitch 2	Pitch 3	Thickness	Radius	Height	Over hang
1	14.08	13.45	14.04	13.91	14.07	13.31	13.58	14.01
2	13.44	14.04	13.86	13.30	13.39	14.00	14.03	13.94
3		13.78	13.37	14.07	13.81	13.97	13.67	13.33
Delta	0.64	0.60	0.66	0.77	0.69	0.69	0.45	0.67
Rank	6	7	5	1	3	2	8	4

Table 7 shows the sequence of factors that have the greatest to smallest influence on slope contact width and tightness force, namely Pitch 3, radius, thickness, Overhang, Pitch 2, length, Pitch 1, height. Based on the results we can know that the radius and Pitch 3 factors have an influence significant enough to design criterion 2.

Based on the S / N ratio graph for criterion 2 as shown in Fig. 9, it is seen that the tilt of the radius and Pitch 3 factors is very large. This shows that the influence of the two factors is very large. On the contrary, the Pitch 1 and height factor slope is very small, which shows the effect is very small. Based on Fig. 9 we also get the optimal design for criterion 2 by selecting each factor's maximum level value. The optimal design of gaskets based on criteria 1 is shown in table 8.

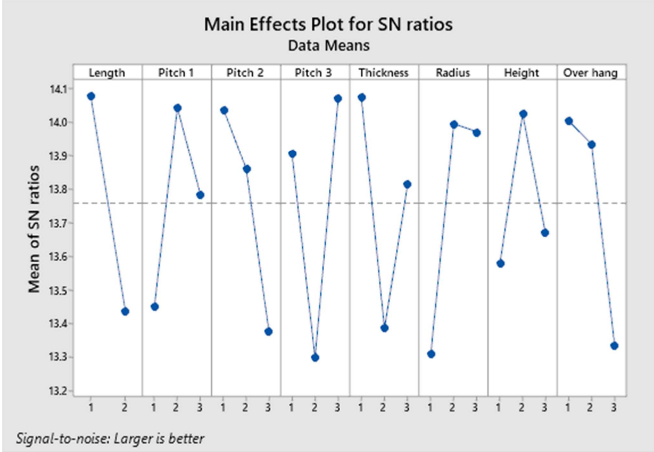

Fig. 11 Plot S/N ratio for criterion 1

TABLE VIII
THE OPTIMUM DESIGN FOR CRITERION 2

No.	Design Parameter	Value
1	Total length (L) [mm]	19.5
2	Pitch 1 (P1) [mm]	3.0
3	Pitch 2 (P2) [mm]	2.5
4	Pitch 3 (P3) [mm]	3.5
5	Thickness (t) [mm]	1.4
6	Radius (R) [mm]	2.5
7	Height (h) [mm]	0.3
8	Overhang (OH) [mm]	2.0

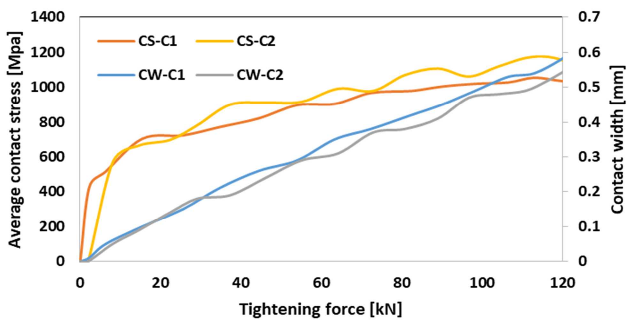

Fig. 12 Contact width and contact stress of criterion 1&2

Table 6 and table 8 show that for design parameter total length, Pitch 1, Pitch 2, Pitch 3 and thickness are the same value. The different values show in the radius, height, and overhang design parameter. Fig. 12 shows the contact width and average contact stress for optimum design of criterion 1 and 2 respectively. The number of contact width for criterion 1 (blue color) is a little more than criterion 2 (grey color) but the average contact stress of criterion 2 (yellow color) tends to higher than criterion 1 (orange color). For more details can be checked on one of the convex parts in this case convex 4, fig. 13, and fig. 14. It appears that the stress that occurs in the convex criterion 2 is higher than criterion 1 so that it will give a better pressure on the flange when in contact at the tightening force is 80 kN, 100 kN, and 120 kN.

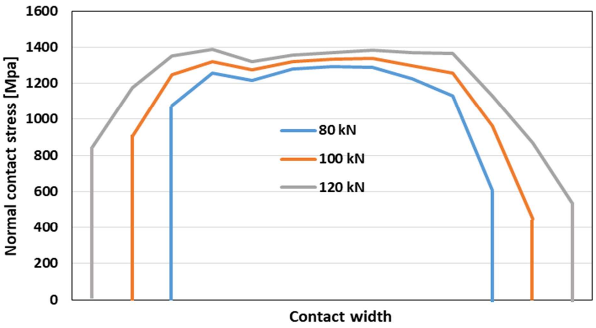

Fig. 13 Contact stress distribution on convex for criterion 1

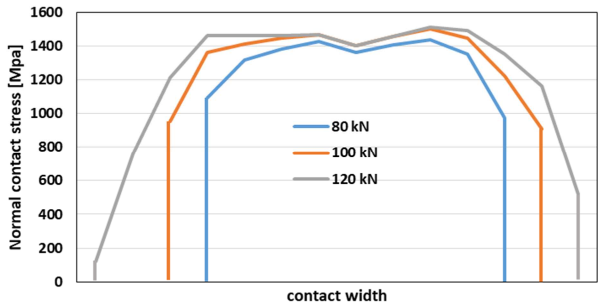

Fig. 14 Contact stress distribution on convex for criterion 2

IV. Conclusions

A new gasket model with a new approach has been introduced. The approach taken in this study uses optimization methods based on the Taguchi and FEM methods; further experimental testing is needed to prove this new gasket model. The results obtained are auspicious and have the potential to contribute positively to the sealing flange joints. Based on the optimization results with the Taguchi method by utilizing the FEM simulation, it is obtained a new gasket parameter design with dimensions total length: 19 mm, Pitch 1: 3.0 mm, Pitch 2: 2.5 mm, Pitch 3: 3.5 mm, Thickness: 1.4 mm, Radius: 2.5 mm, Height: 0.3 mm, and Overhang: 2.0 mm. These results justify the selection of the force per length unit approach as reasonable evaluation criteria.

Nomenclature

F	Force	kN
l	wide of gasket	mm
A	gasket cross section	mm^2
cw	contact width	mm
CS	contact stress	Mpa
Greek letters		
σ	contact stress	MPa
Subscripts		
i	number of data output	

Acknowledgment

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