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Autobody spot-welding optimization based on Genetic Algorithm (GA)

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Abstract

Resistance Spot Welding (RSW) is an important technology that has extensively been applied in the automotive industry. The advantages of this technology are quick and efficient for joining two pieces of metal together. The minimum number of spot welds without decreasing strength has gained much attention from researchers in recent years. In this research, the finite element (FEM) method and the Genetic Algorithm (GA) were proposed to optimize the Spot-welding spacing on automotive aluminum alloy parts. The simulation model was developed to analyze the von Mises stress generated by the side collision on the parts. According to the Insurance Institute for Highway Safety (IIHS) collision test, the computational experiment was designed that the diameter of the steel pipe 180 millimeters perpendicularly collided with the workpiece at the velocity of 14 meters per second to study the maximum stress of the workpiece. This numerical simulation cooperated with the GA for optimizing the spot-welding spacing under the lowest von Mises stress distribution criteria. From the experimental results, it was found that The GA presented the optimal spot-weld spacing on an automotive part. It could reduce the number of spot welds, weld belong-time, and power consumption by 10%. These results demonstrate that the proposed GA is a promising approach for the spot-weld spacing optimization for the Automotive part.

Keywords: Resistance spot welding (RSW), Finite Element Method (FEM), Genetic Algorithm (GA), Equivalent Von Mises stress, Pareto-based Approach.

1. INTRODUCTION

Spot welding technology is widely used in the automotive which is very popular for connecting car parts using sheet metal and for assembling parts in n parts of the structure that are prone to damage because of fatigue under fluctuating loads, according to the physical characteristics of the parts. (Ertas & Sonmez., 2011) The study found that cars one vehicle has a total of 4,800 spot-type resistance spot welding or over 80 percent of the total number of welding. Furthermore, it is expected that the number of connection points will increase in the future of cars significantly (Geißler & Hahn, 2011), which welding will increase the weight of the car and the cost of the department Related to welding. That means it will directly affect the total cost, Therefore, the design is to determine the appropriate distance of the welding point to have the smallest number of welding points under the specified conditions. Without reducing the strength of the welding point, therefore, it is something that researchers attach importance to the study and analysis to improve the quality of the welding point and modernize the production system in the automotive industry.

To address this, many studies in the literature have focused on the optimization of the spot weld distribution using a Meta-Heuristic. And (Zhang & Taylor, 2001) present the optimization problem of a spot-welded structure under fatigue life consideration using the umbrella model considered valid for fatigue life prediction. Besides, (Chae, Kwon, & Lee, 2002) purposed an h-version of adaptive meshing for spot welding locations in shell structures developed. In 2009 (Ertas & Sonmez, 2008) study is to develop a procedure to maximize the fatigue life or the load-carrying capacity of spot-weld joints by minimizing the maximum stress using finite-element analysis software. In addition (Wang, Basu, & Leiva, 2003) presents the design optimization procedure for automobile welds based on the sizing optimization technique to reduce the number of welds and save the cost, while the rigidity requirements are satisfied (Hasegawa, Sasaki, Uehara, & Kawamo, 2007) purposed a meta-heuristic method such an integer optimization method on the discrete type, by using hybrid meta-heuristics for optimization of spot-weld positions, likewise (Hu et al., 2022) present a method of multi-signal fusion to obtain the integrated signal a method of multi-signal fusion to obtain the integrated signal. However, The spot welding sequence has a notable effect on the geometrical variation of the final assembly (Tabar, Wärmefjord, & Söderberg, 2018). Various researchers proposed a multi-objective optimization of the process parameters, through the GA. (Kemda, Barka, Jahazi, & Osmani., 2022) presents the non-dominated sorting GA for minimizing production times and energies through the optimization of process parameters in resistance spot welding (RSW). And (Pashazadeh, Gheisari, & Hamedi, 2016).

RSW is a very fast process, and many factors effected to quality of the welds such as pressure, cycle time, and so on. To find the optimal number of RSW, It is necessary to know the behavior of a spot-welded structure under dynamic loads is strongly influenced by the number and locations of RSW. This paper proposes a method of GA to optimize the RSW spacing on an automotive aluminum alloy body part under the lowest von Mises stress distribution criteria.

2. THEORY AND PRINCIPLES

RSW is an old process that is still being used in welding metal welding in the automotive industry for use in the mass production of automobiles (Salem, 2011). This type of connection method is a low-cost, fast, and convenient way to create automatic welds (Ambroziak & Korzeniowski, 2010), this type of welding process depends on 3 main factors heat, pressure, and time.

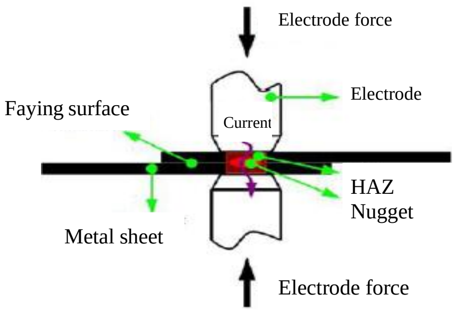


Figure 1 The resistance characteristics of resistance spot welding. (Mali & Inamdar, 2013)

Figure 1 shows the welding of two sheet materials by holding two pieces of welding. Then put pressure on the electrode. So that the current flows through both materials to connect this type of welding appears line in the middle welds. Between the two sheets of material, calling gasket. Nowadays the resistance spot welding method. Using to welding solid workpieces. To increase the strength and reduce fatigue of those parts. And it is the main technique used to weld. The metal parts of the car's body frame. The most in the Current car manufacturing industry. (Gould, 2012) From the survey, the vehicle requires hundreds of robot units for welding. They spot thousands of points from different departments. Resulting in used production time and energy costs.

Figure 2 shows the number of welding types of vehicle type sedan, which was found to have a total of 6,000 welding points and there is resistance spot welding of 4,800 welding points of the total number of welding, which is calculated as a percentage of 80 of the total number of welding points.

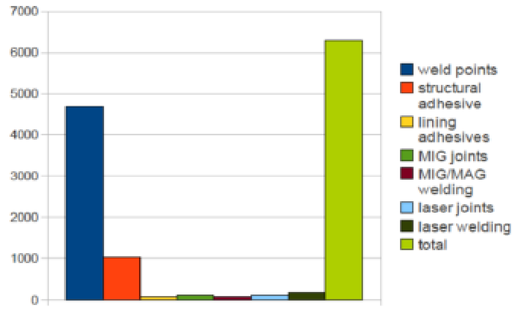


Figure 2 The making of the welded different types of cars. (Geißler & Hahn., 2011)

2.1 Genetic Algorithm

GA is a way to find the answer to optimize the response. That is the principle of the theory of evolution was Charles Darwin. (Zhao, Li, Sun, & Mei, 2009) In the past, the genetic method was used to represent the answer in binary. But now to solve a complicated. Biological theories explain the evolution of life through the mechanism of nature. Selection And heredity are the principle and guidelines for work to develop to be the best answer. Figure 3, shows genetic methodologies, the best answer instead of the binary method (Talbi, 2009).

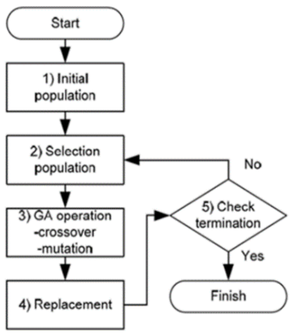


Figure 3 Genetic methodologies.

This is an algorithm the best for solving multi-objective optimization methods. (Al-Mukhtar & Doos, 2013) That is popular and has a good answer percentage of 90. The goal of the method is to approximate the value of the group of true Pareto optimal Solutions. (Jones, Mirrazavi, & Tamiz, 2002) After the development of the Multi-Objective GA in the ANSYS software is the Goal, the direct optimization. And the advantage is suitable for problems with multi-objectives.

2.2 FEM

To design engineering parts, we should first know the carrying capacity of those parts before designing. The FEM is so used as part of the technology for calculating industrial production, by applying a ready-made program for calculating various values. Nowadays car manufacturers use computer software technology to analyze automotive engineering. Problems allowing engineers to improve the quality of parts. With the finite element technique through CAE., It is a method that tests the strength of structural parts. That is popular and reliable in recent years because it can be faster than the actual test. And can reduce the cost of the actual test. The method is a numerical analysis technique for finding the approximate answer to partial differential equations with integrals is a mathematical method that is applied as a program to calculate engineering values such as stress and strain, etc. In designing engineering parts, in design engineering parts, first important know is the load capacity of that part before proceeding with the design. The principles of FEM will start by dividing the problem area into smaller parts called elements (Element) and then considering each element one by one to create an equation for each element the equation created must be consistent with the differential equation of the problem. Then, the value of each element together as a system for the series is bringing all the elements incorporated to make the shape of the real problems. The general procedure of the FEM consists of 6 steps as follows; (ibid.)

Step 1 Dividing the shape. (Figure 4)

Step 2 Selecting the estimation function within the elements that are based on the problem studied.

Step 3 Create an equation for sub-elements.

Step 4 then brings each element's compound into a large set of equations.

Step 5 Apply conditions in a large set of equations to solve unknown equations.

Step 6 When calculating the values, these values are then taken using to find other engineering values such as stress or strain.

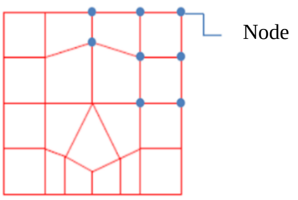


Figure 4 Break the shape of the problem into elements.

2.3 Response Surface Methodology Techniques (RSM).

There are statistical and mathematical techniques used in the design Analyze The experimental. Results for development and improvement to increase efficiency by studying the variables related by having the objectives. To find the suitability for that result. (Montgomery, 2012) Consideration of the response variable must start. By considering the variables that result from finite element analysis such as the deformation value or the stress of the system caused by various inputs etc.

3. EXPERIMENT AND IMPROVEMENT

Figure 5 shows the research methodology of this research

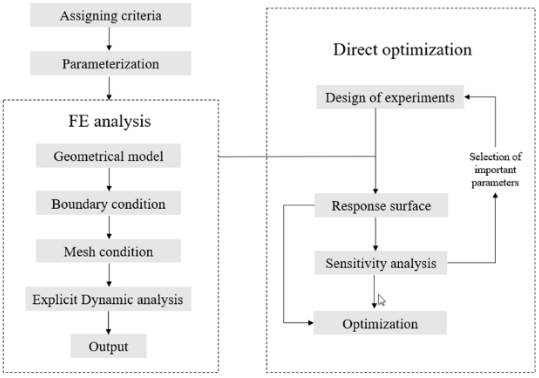


Figure 5 Research methodology

3.1 Automotive body part.

The experimental materials were the B-pillar reinforcement component that is available in all types of cars as illustrated in Figure 6

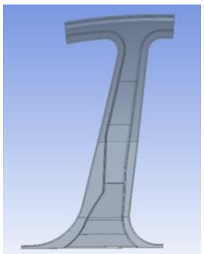


Figure 6 B-pillar reinforcement parts.

The parts are made of Aluminum Alloy 6061-T6. (S. Klimek., 2008), the thickness of 1.2 mm. The diameter of the welding is set according to the standards of The American Welding Society (AWS) and is equal to $4\sqrt{t}$ where t -thickness of the material. Table 1 shows The properties are mechanical of Aluminum Alloy 6061-T6

Table 1 Mechanical properties of Aluminum Alloy 6061-T6 used in the experiment

Item	Crash Test	Ultimate (MPa)	Yield (MPa)	Elongation (%)
Temper T6	Min	337	286	13.6
	Max	340	288	13.9

Table 2 The parameters of RSW

Welding Condition			
Aluminum 6061	Force (kN)	Current (kA)	Time (ms)
	4.5	8	20

3.2 FEM and Explicit Dynamic.

This research considered the parameters of RSW by referring to Table 2 and the location of RSW is divided into 6 lines as shown in Figure 7

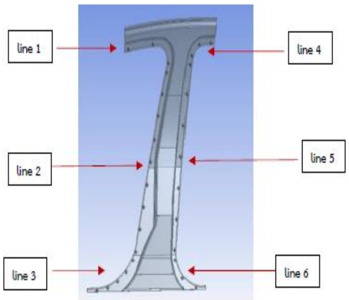


Figure 7 Welding on the B-pillar part.

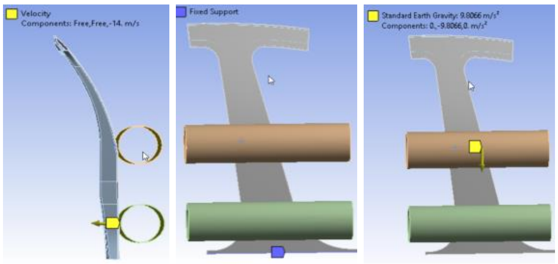
Each line is defined with 3 parameters (Table 3):

1) Start point; SPn
2) Endpoint; EPn and
3) The Number of spot welds; NPn

Table 3 Parameters resistance spot welding of the B-pillar parts

Name	Definition	Original value(mm)
SP1	start point line1	20
SP2	start point line2	20
SP3	start point line3	20
SP4	start point line4	20
SP5	start point line5	20
SP6	start point line6	20
EP1	endpoint line 1	20
EP2	endpoint line 2	20
EP3	endpoint line 3	20
EP4	endpoint line 4	20
EP5	endpoint line 5	20
EP6	endpoint line 6	20
NP1	Number of spot welds line1	3
NP2	Number of spot welds line2	9
NP3	Number of spot welds line3	5
NP4	Number of spot welds line4	3
NP5	Number of spot welds line5	7
NP6	Number of spot welds line6	3

Aluminum tube 180 mm in diameter made from aluminum alloy running into the center of B-pillar parts at a speed of 14 meters per second as illustrated in Figure 8



(a) (b) (c)

Figure 8 The 2 pipes running into the center of B-pillar parts.

3.2.1 Schedule for mesh.

The researcher determined the construction of the mesh as follows;

1. Set the method of creating Mesh as an Adaptive
2. The element size is the default
3. Physical preference: Explicit
4. Quality mesh = High smoothness
5. Growth rate = 1.2
6. Transition = slow
7. Element order = Linear
8. Initial size seed = Assembly
9. Span angle center = coarse

Once all the settings have been configured, the program can create the mesh. (Figure 9)

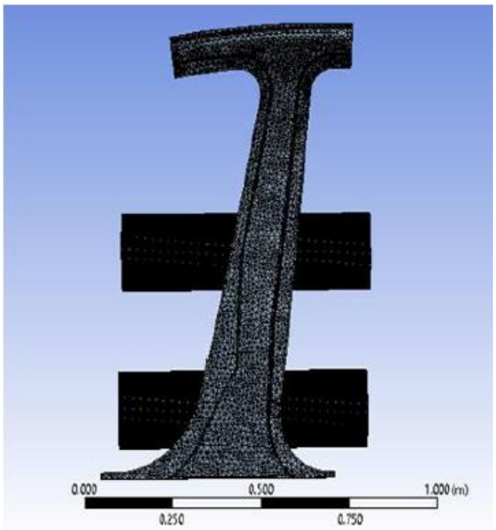


Figure 9 Mesh of parts.

3.3 Using GA in Structural Optimization

After creating the FEM model, the next step is to set up the optimization model. GA is introduced to determine the optimal spacing of RSW. In this research, the parameters in genetic search required by (Gatzi, Uebersax, & Konig, 2000) can be summarized in Table 4, which were searched for various structural problems with ANSYS software and found that the solution was effective.

Table 4 The parameters of GA

Parameters	Value
Initial population	100
Selection population	50
Crossover probability	0.98
Mutation probability	0.01

To generate the offspring and fitness function can be calculated by equations 1 and 2, respectively;

$$\text{offspring1} = \mathrm{a} \times Parent1 + (1 - a) \times Parent2$$

$$\text{offspring2} = (1 - \mathrm{a}) \times Parent1 + a \times Parent2 \quad (1)$$

Fitness function: Minimize σ_e (Vonmises Stress)

$$F(X) = \ (f_1(x), f_2(x), \dots, f_m(x)) \qquad (2)$$

Subject to

$$g_j(X) \ \leq 0 \quad j = 1,2,3$$

$$X_i^l \leq X_i \leq X_i^u \ \ i = 1,2,3$$

Where

$f_i(x)$ - Design component function

$g_i(x)$- the weight of the parameter

X_i^l - The upper bound of the design variable vector.

X_i^u - The lower bound of the design variable vector.

There are 2 conditions to stop the calculation as follows:

1) A Pareto percentage constraint is not more than 70 percent.

2) The value of the objective function initially did not change or there was a large change in the data according to the convergence stability percentage stop condition to find the initial constant based on the mean and standard deviation of parameters in the range of data export.

4. RESULTS

4.1 Analysis of experimental finite elements pre-application genetic.

Experiment with FEM to get the maximum total stress. That occurs on parts with spot resistance from both experiments results as follows;

4.1.1 6061-T6 Aluminum Plate Parts.

Figure 10 shows the distribution of total stress that occurs in a sheet equal to 424.93 MPa Appear is the total stress higher than the stress at the yield point. Resulting in the middle parts becoming deflected and deformed. With the total stress values from the experiment.

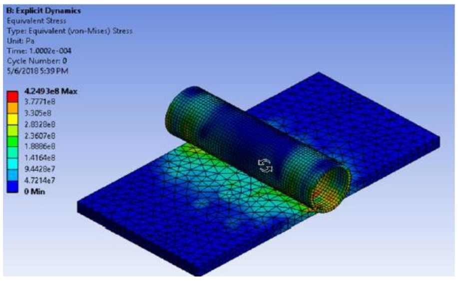


Figure 10 The result of finite element experiment plate parts.

4.1.2 B-pillar part

Figure 11 shows the result of total stress Resulting from the collision speed of two hollow pipes. And using welding parts parameters in Table 3 the maximum total stress is 302.09 MPa

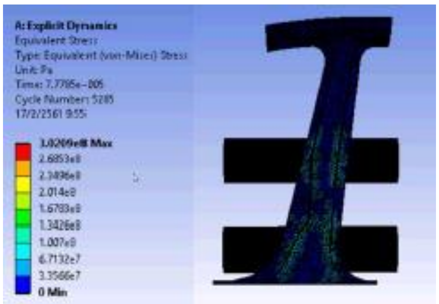


Figure 11 The result of finite element experiment B-pillar.

4.2 Analysis of experimental results with multiple-purpose genetic algorithm.

Bring the value maximum total stress of 2 cases, for the process of finding the appropriate distance between the junction points of the part as follows;

4.2.1 Aluminum Plate Parts 6061-T6.

This section brings the total stress to the optimization process using a multi-purpose GA and the experimental results of finding a suitable value. (Table 5)

The optimization process takes approximately 10 minutes to process. The answer converges design point 343 (Table 5) with the calculation details. Choose the candidate answer 1. Figure 12 shows the convergence conditions which consist of the Pareto percentage graph and the Convergence stability percentage graph. The Pareto percentage graph begins to converge to design point 150 and the Convergence stability percentage design point 300. After that, there is no change or no change. Answer developed.

Table 5 Suitable values of aluminum plate parts 6061-T6

Name	SP1 (mm)	SP2 (mm)	EP1 (mm)	EP2 (mm)	NP1	NP2	σ_{VM} (MPa)
1	2.04	2.04	2.04	2.04	2.04	2.04	169.71
2	2.7673	6.04	2.12	4.7067	3.64	3.1829	-
3	3.4945	4.04	2.2	7.3733	5.24	4.3257	-
4	4.2218	8.04	2.28	2.9289	6.84	5.4686	-
5	4.9491	3.04	2.36	5.5956	8.44	6.6114	-
6	5.6764	7.04	2.44	8.2622	2.36	7.7543	-
7	6.4036	5.04	2.52	3.8178	3.96	8.8971	-
8	7.1309	9.04	2.6	6.4844	5.56	2.2033	-
9	7.8582	2.54	2.68	9.1511	7.16	3.3461	-
10	8.5855	6.54	2.76	2.3363	8.76	4.489	-
11	9.3127	4.54	2.84	5.003	2.68	5.6318	-
…	…	…	…	…	…	…	…
330	2.034	2.077	2.0489	2.049	2.04	2.0352	158.22
331	2.2534	2.077	2.04	2.4977	2.1483	2.1505	173.41
332	2.0285	2.0741	2.0014	2.4982	2.0909	2.1462	167.8
333	2.1253	2.0397	2.0426	2.4971	2.04	2.1453	155.09
334	2.2264	2.915	6.0763	2.0904	2.2785	2.144	195.54
335	2.2348	2.04	6.2304	2.4643	2.04	2.1423	191.17
336	2.1619	2.0357	2.248	2.0811	2.0396	2.1405	175.3
337	2.2291	2.04	6.0752	2.4547	2.04	2.1423	169.28
338	2.245	2.0314	2.2519	2.0005	2.04	2.1453	164.16
339	2.2348	2.0856	6.2529	2.5377	2.04	2.1423	167.01
340	2.0402	2.0398	6.0752	2.04	2.04	2.1423	158.25
341	2.2346	2.04	2.24	2.04	2.04	2.149	178.73
342	2.0403	2.0371	2.04	2.4954	2.04	2.1482	164.57
343	2.1584	2.0812	2.248	2.4985	2.04	2.1405	148.85

Table 6 Suitable values of B-pillar parts

No.	NP1	NP2	NP3	NP4	NP5	NP6	σ_{VM}(MPa)
1	18.02	18.02	18.02	18.02	18.02	-	-
2	4.01	7.17	4.28	2.11	7.05	2.04	-
3	5.01	7.33	4.56	2.20	7.10	2.07	-
4	3.34	7.48	4.83	2.30	7.14	2.11	-
5	4.34	7.64	5.10	2.40	7.19	2.14	-
6	5.34	7.80	5.37	2.49	7.24	2.17	-
7	3.68	7.96	5.65	2.59	7.28	2.21	-
8	4.68	8.12	5.92	2.69	7.33	2.24	-
9	5.68	8.27	6.19	2.78	7.38	2.28	-
10	3.12	8.43	6.46	2.88	7.42	2.31	-
11	4.126	8.59	6.74	2.98	7.47	2.34	-
12	5.126	8.75	4.03	3.07	7.52	2.38	-
13	3.459	8.90	4.31	3.17	7.56	2.41	-
….	…	…	…	…	…	…	…
582	19.944	19.327	7.4331	21.851	18.817	3.1032	289.33
583	19.266	18.99	7.242	18.474	18.754	3.087	292.02
584	18.188	18.118	7.435	18.365	18.06	3.2316	285.91
585	18.005	180.089	7.2597	21.078	18.79	3.229	292.36
586	19.257	18.092	7.4258	18.109	18.182	3.213	291.30
587	19.144	18.93	7.2543	21.515	18.759	3.0886	290.11
588	19.856	18.989	7.396	21.756	20.88	3.007	-
586	19.257	18.092	7.425	18.109	18.182	3.231	295.61
587	19.144	18.93	7.254	21.515	18.759	3.088	292.85
588	19.856	18.989	7.396	21.756	20.88	3.007	-
589	18.258	18.073	7.390	18.051	18.069	2.332	282.366
590	19.935	19.314	7.431	21.763	18.82	3.138	287.91
591	18.031	18.089	7.254	18.109	18.063	3.2299	263.88
592	19.63	18.092	7.4313	21.484	18.182	3.2446	297.43
593	19.944	18.12	7.4331	18.454	18.045	3.1032	294.57
594	18.198	19.214	7.4331	21.668	18.902	3.0767	293.61

*SP1, SP2, SP3, SP4, SP5, SP6, EP1, EP2, EP3, EP4, EP5, EP6 (mm) * σ_{VM} (MPa)

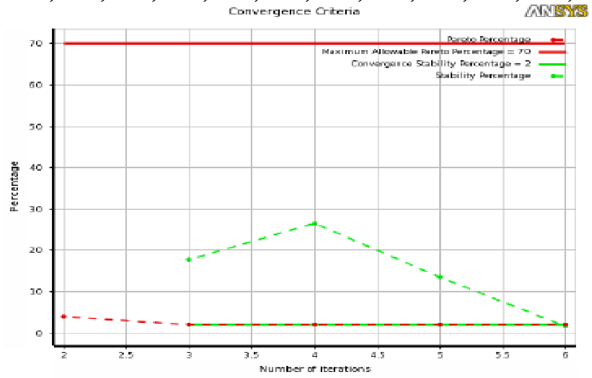


Figure 12 Convergence conditions of aluminum plate parts 6061-T6

4.2.2 B-pillar parts.

The process of finding the suitable value experimental results in Table 6 for finding the 3 best answers.

The optimization process takes approximately 30 minutes to process. The answer converges the design point 594 with the calculation details. (Table 6) Choose the candidate answer 1. Figure 13 shows a graph of convergence. Which consists of the Pareto percentage graph and the Convergence constant line graph. The Pareto percentage graph began converging at the design point at 200, and the design at 150. And both graphs converge at the number of iterations at 11 or around 550. After that, developed no more answers and the calculation stops at design point 594.

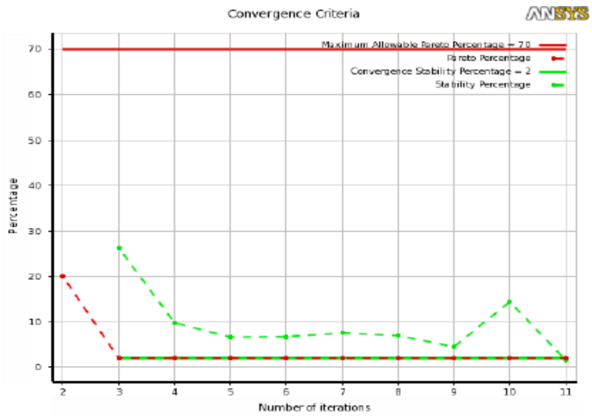


Figure 13 Convergence conditions of B-pillar parts

4.3 Graphic display

Display experimental results in a graphic format. To see the distribution of the total stress value on the part.

4.3.1 Aluminum alloy 6061-T6

After that, take the parameter of Candidate Answer 1 from the experiment in Section 4.1.1. Re-use the Finite Element Analysis program. That the maximum stress equals 139.64 MPa Which is lower than the total stress. Before using Multi-purpose, genetic methodologies which stress equals 424.93 MPa (Figure 14)

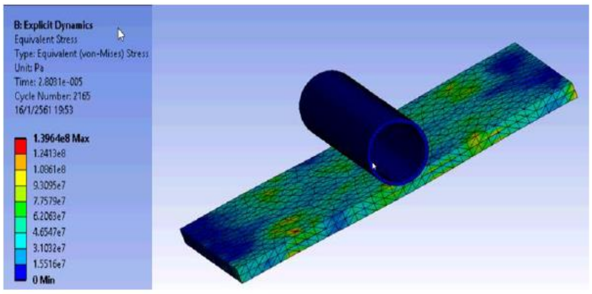


Figure 14 The result of finite elements experiment with 6061-T6 aluminum alloy plate

When bringing the original parameters in Table 1 compare. Found the number of welds reduces by percentage 80 of the original weld number. Cause in the maximum total stress total energy. And the time used to connect the pieces reduces by a percentage of 80 too. (Table 7)

4.3.2 B-pillar part.

After that, take the parameter of Candidate Answer 1 from the experiment in Section 4.1.2 Re-use the Finite Element Analysis program. Figure 15, shows the maximum stress equals 302.09 MPa Which is lower than the total stress. Before using Multi-purpose, genetic methodologies which are stress equals 424.93 MPa when bringing the original parameters to compare. Found the number of welds reduces by percentage 10 of the original weld number. Cause in the maximum total stress total energy. And the time used to connect the pieces reduces by a percentage of 10 too. (Table 8)

Table 7 Parameter comparisons before and after of aluminum alloy 6061-T6 parts

Name	Definition	Before	After	Compare
SP1 (mm)	start point line1	2	2.0368	+0.0368
SP2 (mm)	start point line2	2	2.3065	+0.3065
EP1 (mm)	endpoint line 1	2	2.04	+2.04
EP2 (mm)	endpoint line 2	2	2.0567	+2.0567
NP1 (mm)	Number of welds line1	10	2.024	8
NP2 (mm)	Number of welds line2	10	2.1476	8
σ_x (MPa)	Equivalent von Mises stress	424.93	139.34	285.29

Table 8 Parameter comparison

Name	Definition	Before	After	Compare
SP1(mm)	start point line1	20	21.654	+1.654
SP2(mm)	start point line2	20	18.308	-1.692
SP3(mm)	start point line3	20	18.721	-1.279
SP4(mm)	start point line4	20	18.015	-1.985
SP5(mm)	start point line5	20	19.169	-0.837
SP6(mm)	start point line6	20	21.708	+1.708
EP1(mm)	endpoint line 1	20	21.482	+1.428
EP2(mm)	endpoint line 2	20	20.353	+0.353
EP3(mm)	endpoint line 3	20	19.869	-0.131
EP4(mm)	endpoint line 4	20	19.114	-0.866
EP5(mm)	endpoint line 5	20	18.089	-1.91
EP6(mm)	endpoint line 6	20	18.79	-1.21
NP1(mm)	Number of spot welds line1	3	3.0229	0
NP2(mm)	Number of spot welds line2	9	7.0146	2
NP3(mm)	Number of spot welds line3	5	5.0318	0
NP4(mm)	Number of spot welds line4	3	2.179	1
NP5(mm)	Number of spot welds line5	7	7.4311	0
NP6(mm)	Number of spot welds line6	3	3.2291	0
σ_x (MPa)	Equivalent von Mises stress	302.09	270.16	-32.7

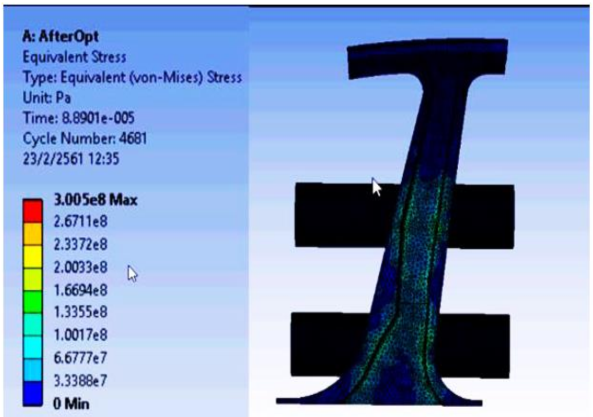


Figure 15 The result of FEM

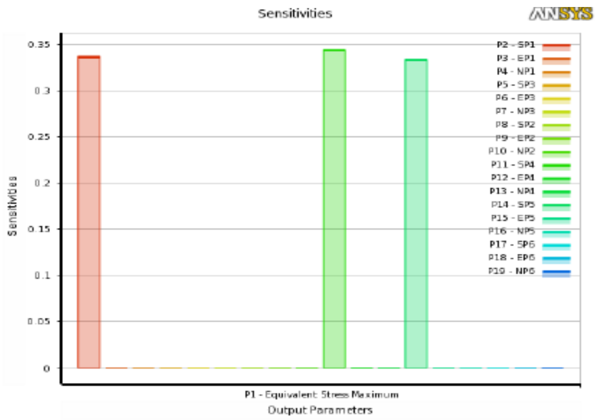


Figure 16 The sensitivity of parameters

4.4 Response Surface Methodology

This was the analysis of a method design to solve problems of design quality. An analysis of experimental. Results for development and improvement to increase parameter efficiency are most suitable, for testing sensitivity analysis next time.

4.5 Sensitivity analysis

Select these parameters to increase the efficiency of the answer with a sensitivity analysis (Figure 16) the graph shows the response sensitivity of parameters (P1) to those changes to the design variable. consists of variables SP1, SP2, SP3, SP4, SP5, SP6, EP1, EP2, EP3, EP4, EP5, EP6, NP1, NP2, NP3, NP4, NP5, and NP6 that have found 3 design variables at the parameter Showed sensitivity such as SP1, SP4, and SP5 with response sensitivity of 0.33743, 0.34463 and 0.33426 respectively.

5. Conclusion

1. Parameters that have the highest total stress values parameters had P3, P12, and P15 had the highest influence on total stress considering the response sensitivity analysis with values of 0.33743, 0.34463, and 0.33426 respectively.

2. Application of genetic methods to determine the distance of the resistance spot welding by Application of a multi-purpose genetic algorithm to find the suitable distance of the welding The results of both before and after the experiment showed that in the Number of welding points, Total energy value And the time it takes to connect the Aluminum alloy 6061-T6 plate parts is reduced to percentage 80 and in the B-pillar parts Number of welding points, total energy value and the time used to connect the pieces is reduced to 10%.

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