Effect of Spot-Welding Parameters on the Strength of the Weld of Metal Sheets

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Abstract

Resistance spot welding is one of the most common welding techniques used in the automotive and aviation industries. In the present research, the effect of resistance spot welding parameters such as, holding time, squeeze time, welding current, force applied, and welding time will be examined using Simufact Welding 2020, a welding simulation application. The impact of these parameters on the strength of the weld in metal sheets are studied. Each parameter was studied separately by changing one parameter within the range values and other parameters as constant values. It was found that the best region for the following spot-welding parameters is, from 0.9 s to 0.95 for squeeze time, 6.5 kA to 7.5 kA for welding current, 0.15 s to 0.4 s welding time, 30 ms for holding time, and 3.2 kN to 3.4 kN for electrode force. These parameter ranges are best to provide a spot weld with the highest yield stress.

Keywords
Resistance Spot Welding, Simulation, Automotive, Metal Sheets, Manufacturing

1. Introduction
Resistance spot welding (RSW) is a powerful welding technique that can be generally used on thin metal sheets. For thick metal sheets specialized heavy duty equipment's are used. This method allows for a quick welding process and the production of joints with high strength quality. Unlike other welding processes, spot welding does not use filler material to join two parts, or the electrode doesn't melt during the process. Meanwhile the electrodes, which are typically made of highly electrical and thermally conductive materials such as copper, are clamped to both sides of sheets and the current is applied. The generated heat melts the metal while the pressure from the electrodes squeezes the molten metal to form a weld. It is primarily used in the production of automobiles. This is accomplished in a matter of seconds by spot welding robots. When working on a car body, however, sheet metal shops employ less sophisticated methods. The Basic mechanism of resistance spot welding is shown below in figure 1.

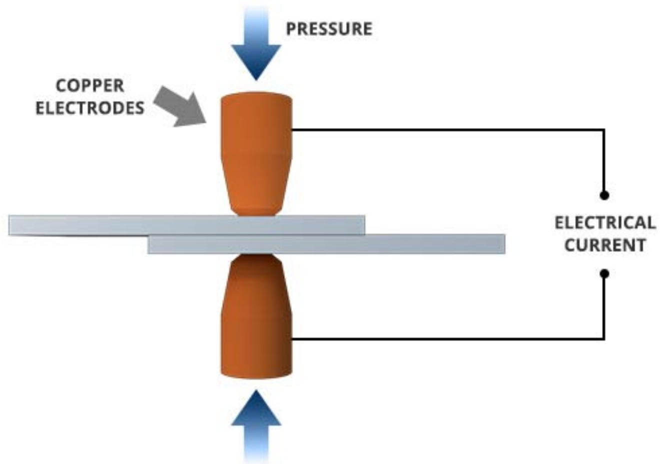

Figure 1. Mechanism of resistance spot welding

RSW process parameters are one of the main factors that affect the weld spot. Main process parameters are welding current, anode shape, electrode force, welding time, holding time, squeeze time. So, finding the best values for each parameter will help to minimize the production time. The time consumption per spot weld is considerably small on a small scale, however, on a large scale such as vehicle manufacturing industry the time consumption per spot weld is crucial to optimize the industry.

1.1 Objectives

The time consumed by resistance spot welding in major industries, like the automotive industry, has not been widely reported. This research aims to examine the contribution of welding current, welding time, squeeze time, hold time, and welding force on resistive spot welding, using Simufact welding simulation software. The assessment will be performed by evaluating the yield strength from each parameter. The variation in the result produced will determine the trend line of the parameters distinctly. The research will also assist in determining the optimum range required for the automotive industry to produce the desired weld while maintaining an acceptable time frame for the RWS process.

The following are the main objectives:

- Highlight the importance of RWS on the time consumption in the Automotive field.
- Examine several parameters of RWS such as welding time, welding strength, hold time, squeeze time, welding force.

2. Literature Review

In many studies, the effect of welding parameters was investigated to find the impact in the output. Ghanbari H et al. (2022) studied the effect of spot-welded parameters on Fatigue behavior of resistance spot welding in ferrite-martensite dual-phase steel joints with one, three, and hybrid welds. The results show that electric current has a greater effect on fatigue life than other parameters, but its effectiveness diminishes as it increases. Tyagi A et al. (2021) experimentally investigated the optimization of robot spot welding parameters. The Taguchi L18 methodology was used to optimize the spot-welding process parameters on a low carbon steel grade (JSC 590RN). It was shown that the welding current (39.19%) participates the most, followed by weld time (23.81%). Biraadr A and Dabade B (2019) experimentally analyzed the effect of different welding parametric range on austenitic stainless steel and mild steel sheet. By utilizing ANOVA analysis, it was revealed that the weld current has the largest effect, while clamping force has the least in spot welding. Farrahi G et al. (2020) investigated the effects of spot-welding process parameters on spot-welded joint nugget diameter and electrode penetration depth. The Taguchi analysis revealed that the electrical current (22%) and welding time (17%) are the most effective factors on nugget diameter. Fatmahardi I et al. (2021) carried an experiment using the Taguchi L9 method to determine the optimum level of weld joint strength in titanium alloy Ti-6Al-4V. The result showed that in the fusion zone, the combination of high heat input and rapid air cooling at room temperature resulted in a martensite microstructure. The results showed that hardness, strength, and brittleness were improved while ductility decreasing.

Welding parametric range is another factor which needs to be considered while simulating resistance spot welding. For each parameter there is a particular range of values. S. Aslanlar et al. (2007) studied the effect of welding current on steel sheets in resistance spot welding and the welding current was increased from 4 to 12 kA. Experimental studies were conducted by Uğur Eşme (2009) under varying electrode forces, welding currents, electrode diameters, and welding times for optimization of resistance spot welding. The range of welding current was in between 6 to 15 KA. The impact of welding current on resistance spot welding was analyzed by (Wan X. et al. 2014). The welding current was increased from 6KA to 12KA. Therefore, from the above studies, the range of welding current in this research will be taken from 6KA to 12KA. The effect of electrode force on resistance spot welded dual phase steel joints were studied by (Rajarajan C et al. 2020). The electrode force range was increased from 3.6 to 4.8 MPa. Similarly welding time on low carbon steel resistance spot welds was taken between 5-9 cycles by (M. Pouranvari 2011). Therefore, in this study, the parametric range are taken as follows. Welding current 6-12kA, electrode force 2.8- 4.4kN, squeeze time 0.8 to 1.2s, welding time 0.01 to 0.7s, hold time 10 -100ms.

3. Simulation Modeling Method

In this research, simulation is done using Simufact Welding 2020, which is the latest finite element simulation tool available. There are many parameters that can affect the welding process, each parameter will be studied separately. The main parameters are hold time, welding current, welding time, welding force, and squeeze time. The effect of each parameter will be recorded by maintaining all other parameters to constant values and changing one parameter within the range.

At the beginning of the experiment, it is important to eliminate other possible error factors that may affect the welding process. Therefore, the metal sheet sizes are taken constant to be of the dimensions 150×200×2 mm. Given the dimensions of the metal sheets, the error that can happen due to changing sheet dimensions is restricted. Moreover, another parameter that is kept constant in this experiment is the locations of the clamps. As shown in the Figure 2 below, the locations of the 4 clamps used in the simulations is one the exact edges of where the plates overlay.
This study uses Simufact welding 2020, in modeling and simulating the resistance spot welding process. The simulation software is equipped with a library of materials. At the beginning, it is important to make sure that the units used for measurement of length is in meters.

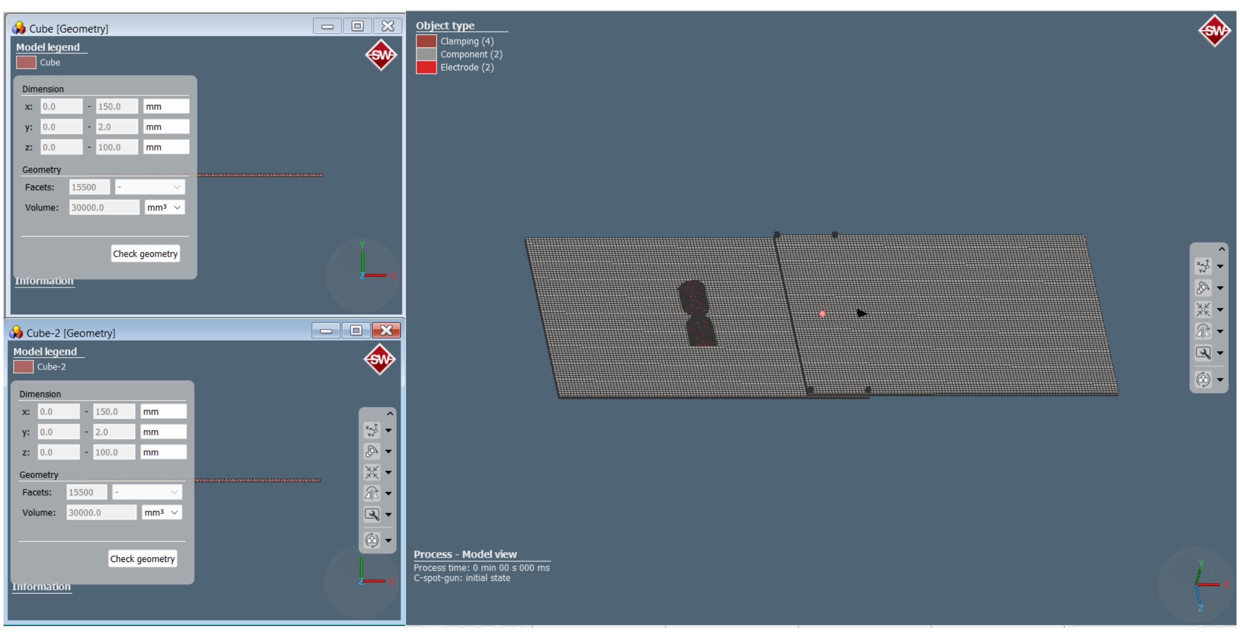

Figure 2. Sheets dimensions on Simufact

The simulation process was defined in the simulation software with the following settings:

- The number of components is set to be at 2
- The number of clamps is set to be 4
- C spot gun was set to 1
- Bainite phase fraction of the metal sheets is set to 100.0%
- Contact heat transfer coefficient ∝ set to automatic
- Overlap of the two sheets is set to be 20 mm
- The material of the sheets was assigned to be 22MnB5-JMP-MPM_sw
- The ambient temperature was set at 20°C
- The two anode electrodes used are made from Cu_sw
- Anodes radius is 3 mm
- Refinement level set to 1
- Time control of the experiment was set to be 10 seconds
- Number of domains is 1 and numbers of cores is 4

The simulation ran for 43 times with the same main settings. However, with one changing parameter while the other parameters are kept constant to study the effect of the changing parameter. The variation in each parameter is shown in the table below, Table 1.

Table 1. Parameter variations

Parameter	Variation
Squeeze time [s]	0.8, 0.85, 0.9, 0.95, 1, 1.05, 1.1, 1.15, 1.2
Welding current [kA]	6, 7, 8, 9, 10, 11, 12
Welding time [s]	0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.63, 0.7
Hold time [ms]	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Electrode force [kN]	2.8, 3, 3.2, 3.4, 3.8, 4, 4.2, 4.4

4. Results and Discussion

4.1 Squeeze Time

In these set of runs, a total of 9 runs, the effect of squeeze time on the strength of the weld was tested. There was a variation in the squeeze time variables taken, while keeping the other parameters constant. The holding time was set to be of 10 ms, welding time 0.1 s, welding current 6 kA, and the electrode force was kept constant at 3 kN. An example of this simulation is shown in Figure 3.

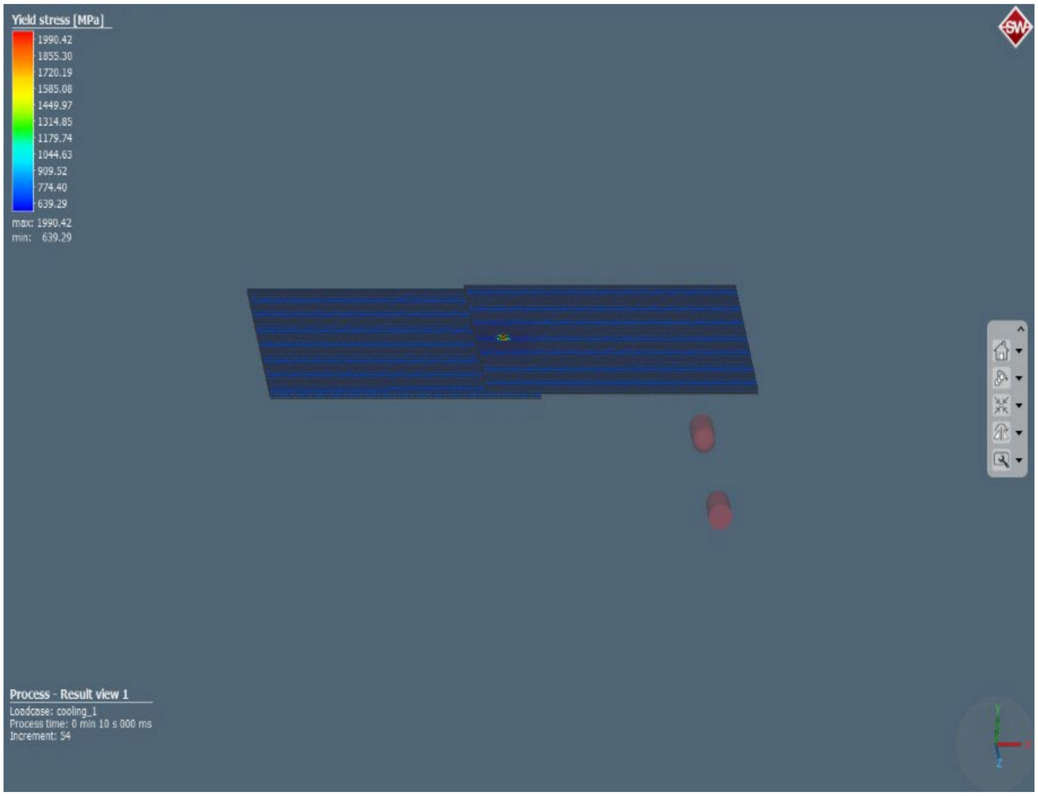

Figure 3. Maximum yield stress simulation for squeeze time

The following table, table 2, expresses the set of runs made and the recorded variables.

Table 2. Squeeze time results

Squeeze time [s]	Holding time [ms]	Welding time [s]	Welding current [kA]	Electrode force [kN]	Yield stress [MPa]
0.8	10	0.1	6	3	1918.68
0.85	10	0.1	6	3	1918.09
0.9	10	0.1	6	3	1984.21
0.95	10	0.1	6	3	1990.42
1	10	0.1	6	3	1963.30
1.05	10	0.1	6	3	1961.58
1.1	10	0.1	6	3	1947.36
1.15	10	0.1	6	3	1909.96
1.2	10	0.1	6	3	1905.07

After the simulation, it was noticed that there was a continuous increase in the yield stress of the welded metal sheets when squeeze time was from 0.85 s peaking at around 0.9 s. However, after the 0.95 s, there was a continuous decrease in the yield stress of the welded metal sheet shown figure 4.

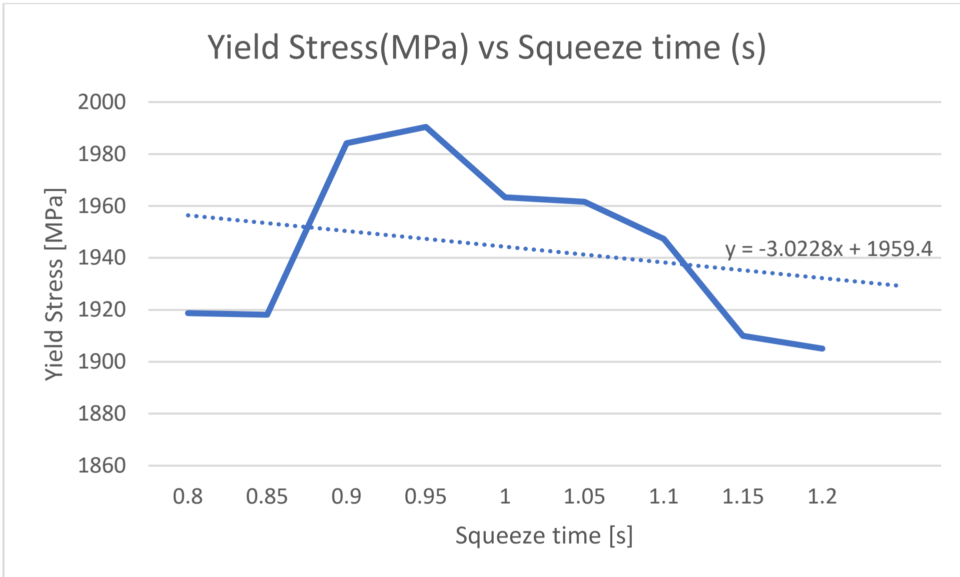

Figure 4. Squeeze time results

4.2 Welding Current

A total of 7 runs were made to test the effect of welding current on the strength of the weld made. All parameters were kept constant while the welding current was changing. The squeeze time was kept at 0.8 s, holding time 10 ms, welding time 0.1 s, and electrode force 3 kN. Figure 5 shows an example of the simulation for welding current.

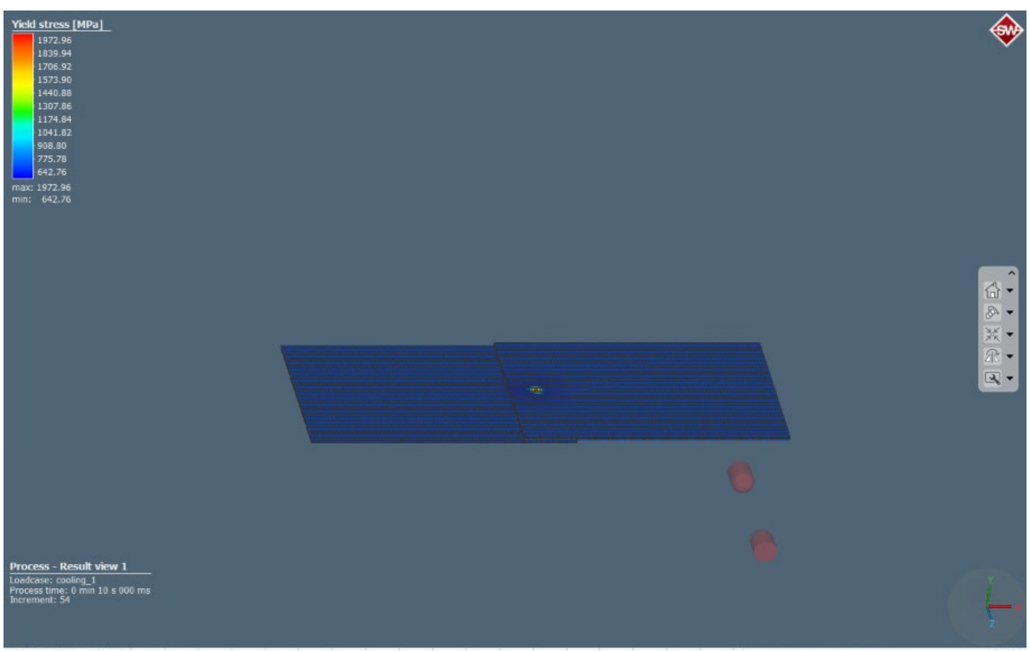

Figure 5. Maximum yield stress simulation for welding current

In table 3, there variation of welding current with respect to the other parameters is expressed. Moreover, the yield stress recorded from Simufact is presented in the last column.

Table 3. Welding Current Parameters and Results

Squeeze time [s]	Holding time [ms]	Welding time [s]	Welding current [kA]	Electrode force [kN]	Yield stress [MPa]
0.8	10	0.1	6	3	1966.14
0.8	10	0.1	7	3	1972.96
0.8	10	0.1	8	3	1909.11
0.8	10	0.1	9	3	1798.13
0.8	10	0.1	10	3	1873.12
0.8	10	0.1	11	3	1798.50
0.8	10	0.1	12	3	1857.37

In the figure 6, it can be noticed that at 7kA, maximum yield has been obtained. The simulation showed a significant decrease in yield stress between 7 kA and 9 kA.

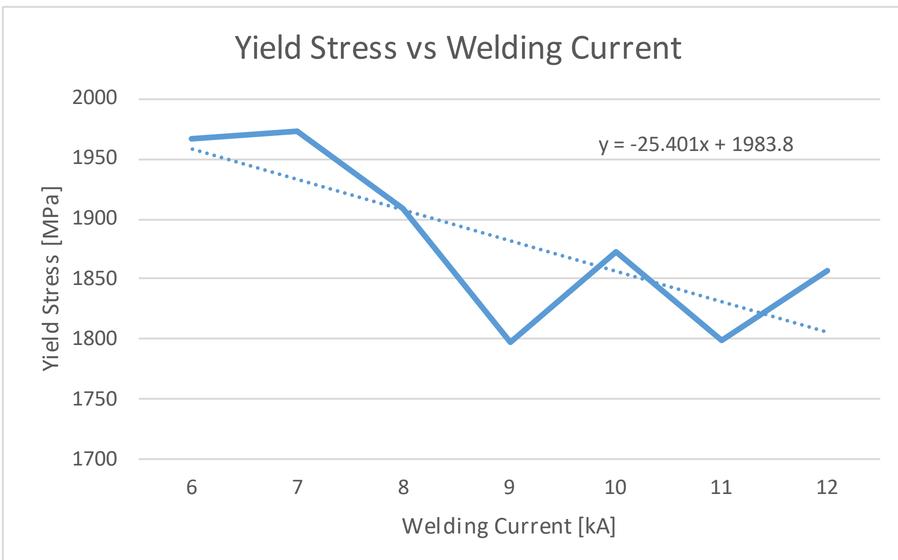

Figure 6. Welding Current results

4.3 Welding time

The welding time range was from 0.01 s to 0.7 s, therefore, 9 runs were made with different welding time variables. All parameters other than the welding time were kept constant. The squeeze time was kept at 0.8 s, holding time 10 ms, welding current 6 kA, and the electrode force at 3 kN. Figure 7 shows the simulation run for welding time.

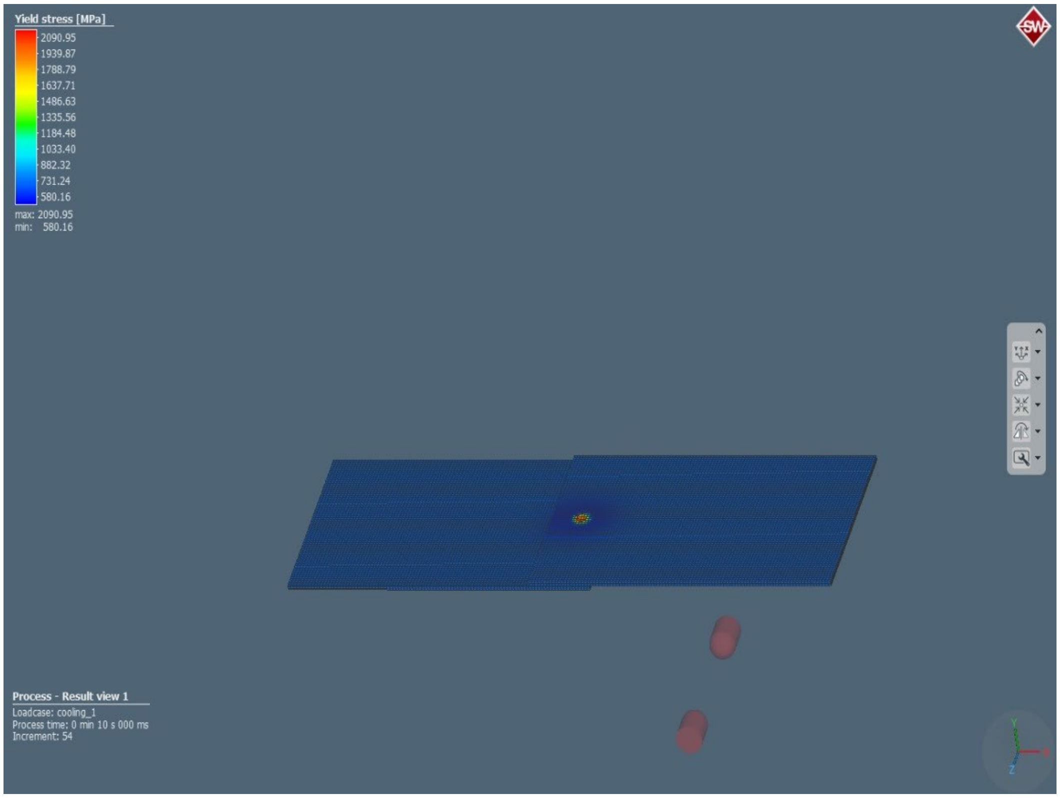

Figure 7. Maximum yield stress simulation for welding time

The table below, Table 4, presents all runs with respect to the yield stress.

Table 4. Welding Time Parameters and Results

Squeeze time [s]	Holding time [ms]	Welding time [s]	Welding current [kA]	Electrode force [kN]	Yield stress [MPa]
0.8	10	0.01	6	3	914.52
0.8	10	0.1	6	3	1927.69
0.8	10	0.2	6	3	2132.56
0.8	10	0.3	6	3	2152.97
0.8	10	0.4	6	3	2060.22
0.8	10	0.5	6	3	2063.01
0.8	10	0.6	6	3	2090.95
0.8	10	0.63	6	3	2088.83
0.8	10	0.7	6	3	1990.82

In the figure 8, it was noted that the yield stress increased drastically when welding time was from 0.01 s to 2 s. An increase with a slower rate was seen from 0.1 s till around 0.6 s, peaking at 0.6 s. After the 0.6 s the yield stress was noticed decreasing.

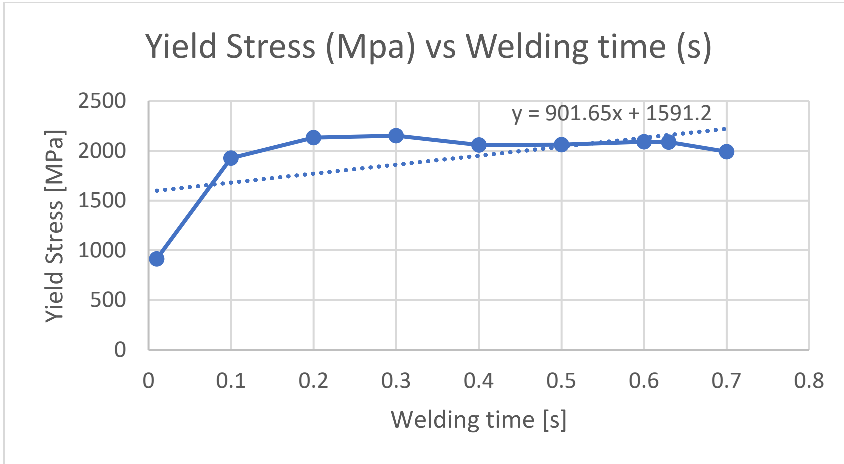

Figure 8. Welding Time results

4.4 Hold Time

A total of 9 runs with different variations in welding time was made to measure the effect of hold time on the yield stress of the weld. The range of hold time was set to be from 10ms to100ms. While all other parameters were kept constant. The squeeze time was kept 0.8 s, welding time 0.1 s, welding current 6 kA, and electrode force at 3 kN. An example of the simulation for holding time is shown in Figure 9.

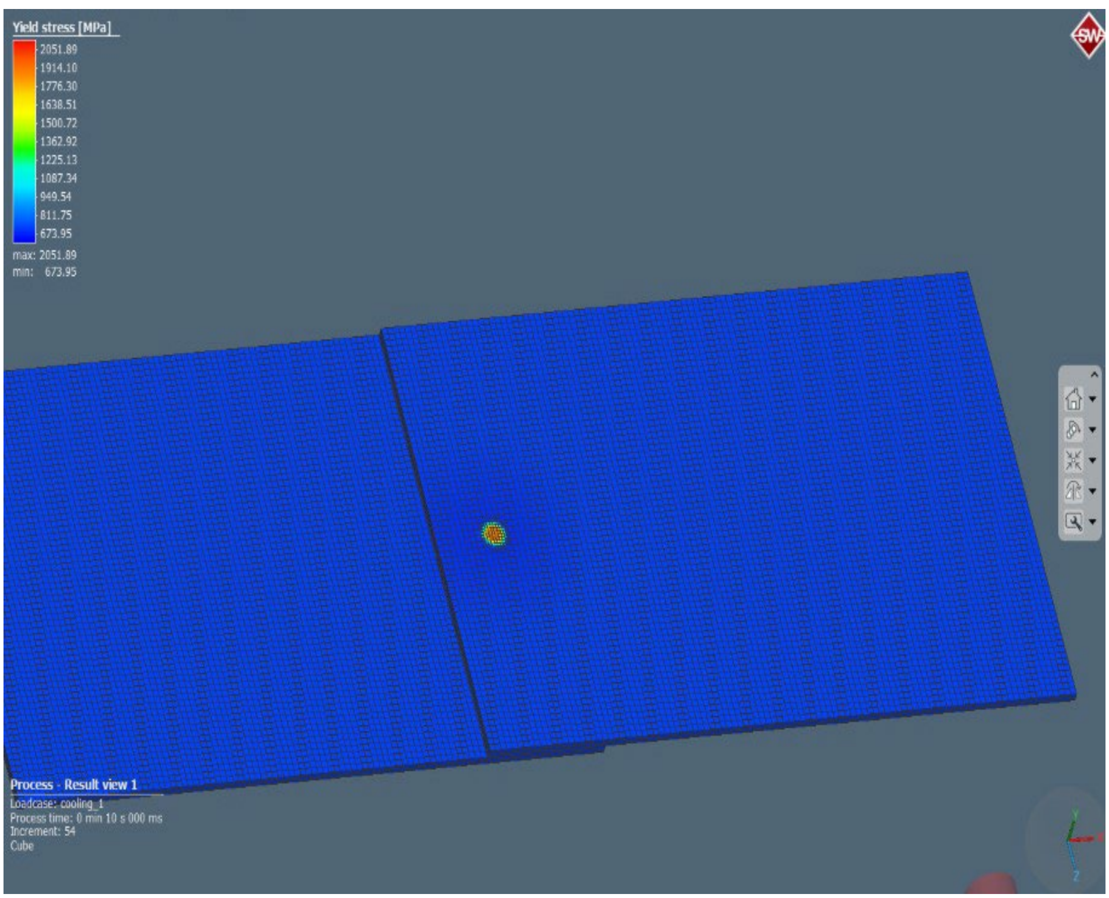

Figure 9. maximum yield stress simulation for holding time

The table below, expresses the parameters and results acquired from the simulations.

Table 5. Hold time Parameters and Results

Squeeze time [s]	Holding time [ms]	Welding time [s]	Welding current [kA]	Electrode force [kN]	Yield stress [MPa]
0.8	10	0.1	6	3	2022.34
0.8	20	0.1	6	3	2025.90
0.8	30	0.1	6	3	2182.09
0.8	40	0.1	6	3	2035.76
0.8	50	0.1	6	3	2030.09
0.8	60	0.1	6	3	2037.30
0.8	70	0.1	6	3	2037.83
0.8	80	0.1	6	3	2002.00
0.8	90	0.1	6	3	2051.89
0.8	100	0.1	6	3	2076.77

From the figure 10, it was seen that the highest yield stress was achieved between 20 ms and 40 ms at around 30 ms of hold time. However, throughout the other time, the effect of hold time on the yield stress of the welded joint is not noticeable. Between 70 ms and 90 ms, there was a decrease in the yield stress and the minimum yield stress was reached at 80 ms with a yield stress of 2002.00 MPa.

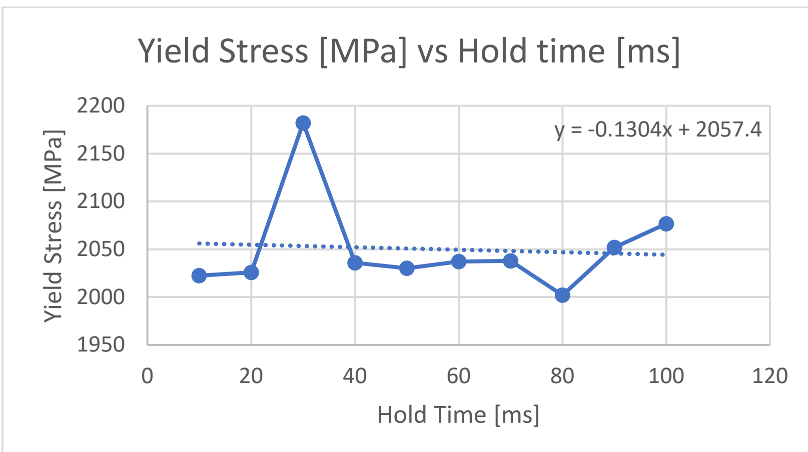

Figure 10. Hold time results

4.5 Electrode Force

For welding force, the range determined was from 2.8 kN to 4.4 kN, there were 8 runs to study the effect of the electrode force on the yield stress. The squeeze time was constant considered to be 0.8 s, welding time 0.1 s, holding time 10 ms, welding current 6 kA. Figure 11 shows an example of the simulation under the above setting.

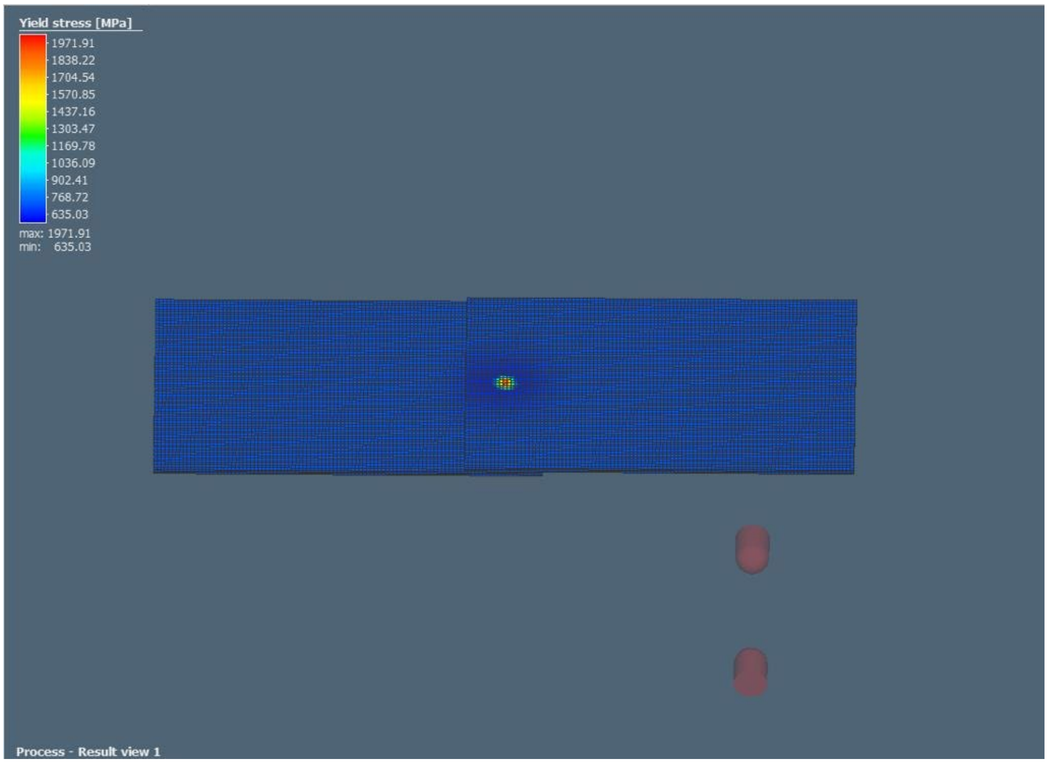

Figure 11. maximum yield stress simulation for electrode force

The following table will express the yield stress collected from the input parameters inserted.

Table 6. Electrode Forces Parameters and Results

Squeeze time [s]	Holding time [ms]	Welding time [s]	Welding current [kA]	Electrode force [kN]	Yield stress [MPa]
0.8	10	0.1	6 kA	2.8	1965.40
0.8	10	0.1	6 kA	3	1910.49
0.8	10	0.1	6 kA	3.2	1971.28
0.8	10	0.1	6 kA	3.4	1971.91
0.8	10	0.1	6 kA	3.8	1945.17
0.8	10	0.1	6 kA	4	1935.52
0.8	10	0.1	6 kA	4.2	1956.85
0.8	10	0.1	6 kA	4.4	1952.95

As illustrated in figure 12, there was a decrease in strength of the weld between 2.8 kN and 3.2 kN with a minimum of 1910.49 MPa at 3 kN. However, it was noticed that the highest weld strength was between 3.2 kN and 3.4 kN, a maximum yield strength reached between the runs was at 3.4 kN with a yield stress of 1971.91 MPa. The difference both runs on 3.2 and 3.4 was very minimal with a difference of 0.63 MPa. On the other hand, after 3.4 kN there was a continuous decrease in the yield stress of the weld throughout the rest of the runs.

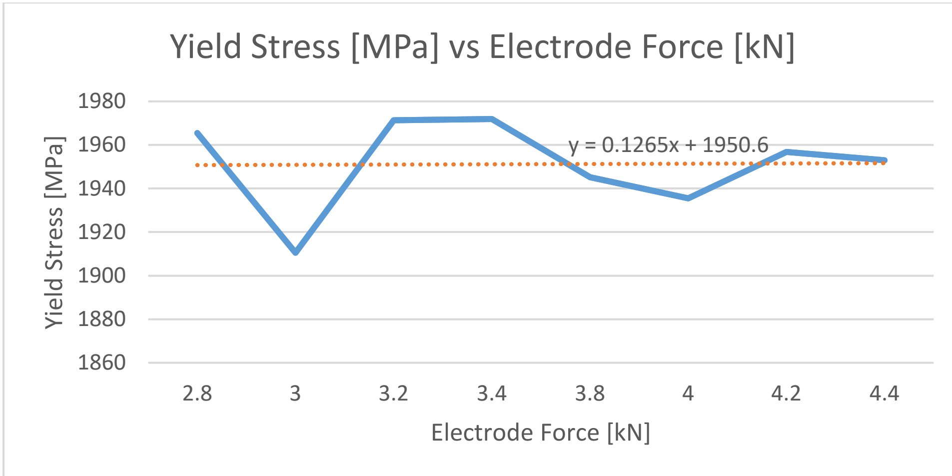

Figure 12. Electrode force results

5. Conclusion Further Research

As for future research, further exploration for other spot-welding parameters that can affect the yield stress of the spotted weld such as, radians of the c-gun, the shape of the electrode rods and type of material. All of these parameters have an effect on the strength of the spotted weld affecting the quality and properties of the final product. Furthermore, using Matlab to find a formulate a prediction model and optimization equation of the experiment is advised as using the latest technology in research would allow to obtain more accurate and precise readings.

6. Conclusion

The present study attempted to simulate the effect of various welding process parameters on spot weld quality by analyzing the yield stress. The Simufact 2020 welding simulation application was used to determine the maximum yield stress for each parameter. The simulations were performed by using the same initial file that contains the clamps to prevent any error that may be caused due to difference in positioning of clamps or in position of the spot weld. The effect of spot-welding parameters was achieved by keeping all parameters constant and changing the studied parameter within the range. The yield stress was collected after each run and summarized in graphs to understand basic trends and relationships between each set. It was found out that the highest yield stress welds can be performed at a holding time of 0.9 ms to 0.95 ms, welding current between 6.5 kA to 7.5 kA, welding time between 0.15 s to 0.4 s, hold time of 30 ms, and electrode force between 3.2 kN and 3.4 kN. The trends were characterized by a positive linear relationship. These conditions resulted in highest values of recorded yield stress of the spot welded. Therefore, the effect of each parameter on yield stress were found out using the simulation.

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Biography / Biographies

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