Research Paper

Tensile Testing and Macrographic Examination of Resistance Spot Welding on Aluminum–Copper–Magnesium Alloy Sheet in Accordance with AWS D17.2

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Abstract

The growing use of aluminum alloys in modern aerospace structures requires reliable and standardized joining methods to ensure structural integrity and weight efficiency. Resistance spot welding (RSW) offers a promising alternative to mechanical fastening and fusion welding due to its high speed, low cost, and suitability for thin-sheet materials. This study evaluates the feasibility of RSW on 2024-T42 aluminum sheets with dissimilar thicknesses of 0.6 mm and 0.8 mm in accordance with American Welding Society AWS D17.2. Pre-production specimens were tested using tensile shear and macrographic analyses following ASTM International ASTM E8 and ASTM E340 standards. The average tensile shear load was 318.22 lbf, exceeding the minimum requirement of 235 lbf. Penetration depth (45–55%) and indentation (<0.10 mm) also satisfied the acceptance criteria, while surface resistance prior to welding remained below 50 μΩ. These results confirm that RSW of 2024-T42 aluminum sheets with dissimilar thicknesses meets AWS D17.2 requirements and demonstrates its potential as a technically viable and efficient joining process for lightweight aerospace structural components.

Keywords *Resistance spot welding, 2024 T42 aluminum-copper-magnesium alloy, AWS D17.2, Tensile shear test, Macrographic analysis*

INTRODUCTION

In the manufacturing of aerospace products, material selection plays a crucial role (Wibawa, 2019). The most commonly used materials for aircraft skin, including the fuselage and wing surfaces, are aluminum and its alloys, which often contain elements such as zinc, magnesium, and copper. For over 80 years, aluminum alloys have been effectively utilized as the primary materials in aircraft structural components due to their proven performance, well-established design methods, efficient manufacturing processes, and reliable inspection techniques (Dursun, 2013). In recent years, joining technologies for aluminum alloys have advanced significantly, especially in lightweight aerospace applications (Dada et al., 2024).

Welding technology is one of the key joining methods in manufacturing. Welding joins two or more metals by applying heat (Hendaryati, 2022). Among various welding methods, resistance spot welding (RSW) is widely used in aerospace applications. RSW is a complex process that involves interactions among electrical, thermal, mechanical, and metallurgical factors (Haghshenas, 2019). Because aerospace production requires high safety and reliability, strict industrial specifications are applied, such as AWS D17.2, issued by ANSI, which governs the use of RSW machines and sets quality requirements for welded aerospace components.

The objective of this study is to evaluate the technical feasibility of RSW on Al 2024-T42 thin plates with a thickness combination of 0.6 + 0.8 mm. Pre-production welded specimens were

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examined through tensile shear and macrographic analyses. The results are compared against AWS D17.2 requirements to assess the compliance and reliability of the RSW process for aerospace applications.

LITERATURE REVIEW

Aluminum Alloys

Aluminum alloys, often referred to as lightweight alloys, were developed to enhance the strength of pure Aluminum, which is naturally malleable and corrosion-resistant. The principal alloying elements include magnesium, silicon, zinc, copper, and manganese (Mazzolani, 1994). The 2000 series Aluminum alloys, with copper as the dominant alloying element, are commonly produced in the form of extrusions, plates, and pipes. When subjected to heat treatment, their strength can reach up to 300 N/mm^2 (0.2% proof stress), with a ductility of around 10%. However, their corrosion resistance is relatively low. Due to their limited weldability, these alloys are not widely used in civil engineering; however, they are extensively applied in the aviation industry.

Aluminum 2024, a member of the 2000 series, is a wrought alloy that can be strengthened by heat treatment, with Al–Cu as its primary alloying system (Koesgi, 2021). Despite its high strength, Aluminum 2024 exhibits poor corrosion resistance, which is why it is often clad with pure Aluminum or alloys from the 6000 series to enhance surface protection. A typical composition of Aluminum 2024 includes 0.5% Si, 0.5% Fe, 3.8–4.9% Cu, 0.3–0.9% Mn, 1.2–1.8% Mg, 0.25% Zn, and 0.15% Ti. While copper increases hardness and strength, it can also trigger black smutting and intergranular attack, reducing corrosion resistance.

Welding

Welding is a process of permanently joining two or more materials, typically metals, by applying localized heat and pressure under specific metallurgical conditions (Khan, 2007). As noted by Wiryosumarto (2000), “welding is not the ultimate goal of construction, but rather a means to achieve better economic aspects of manufacturing.” Therefore, the selection of a welding process must be tailored to the type of joint and construction requirements, taking into account factors such as efficiency, cost, labor, and energy (Bakhori, 2017). Among the various welding processes developed, resistance spot welding (RSW) has been widely adopted, particularly for applications involving thin sheets.

Resistance Spot Welding

Resistance Spot Welding (RSW) is a joining method commonly applied to thin metal plates, where an electric current passes through electrodes that press against the material, generating heat due to surface resistance until localized melting occurs. Once the current is interrupted, pressure is maintained to solidify the joint. To avoid overheating, electrodes are typically made of copper or its alloys due to their high electrical conductivity, and are equipped with water-cooling systems (Priyotomo, 2021). RSW offers several advantages, including neat joint formation, short processing times, and ease of automation. However, welding quality strongly depends on parameters such as cooling conditions, current magnitude, and electrode force duration. The process consists of four primary cycles (Sahrevy, 2021):

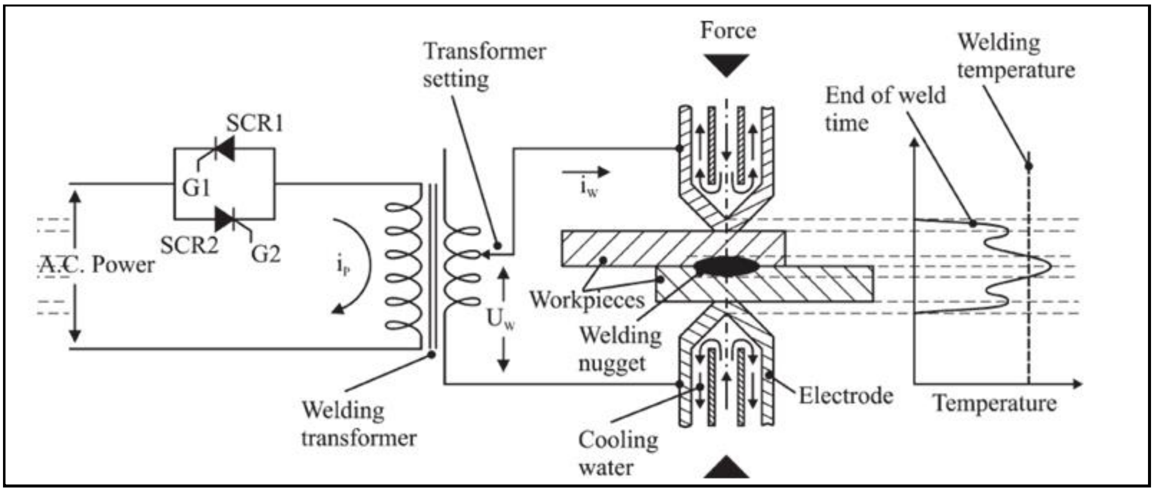


Figure 1. Schematic of RSW

Source: Podržaj, (2008)

The result of the heat formation at the interface of the workpiece/workpieces is an increase in temperature exceeding the welding temperature. As a result, a volume of material (known as the weld nugget) is formed between the workpieces. The size (diameter) of the weld nugget is very important, as after cooling, this size determines the strength of the weld. If other parameters remain constant, the size of the weld nugget increases with welding time, as shown in Figure 2 (Podržaj, 2008).

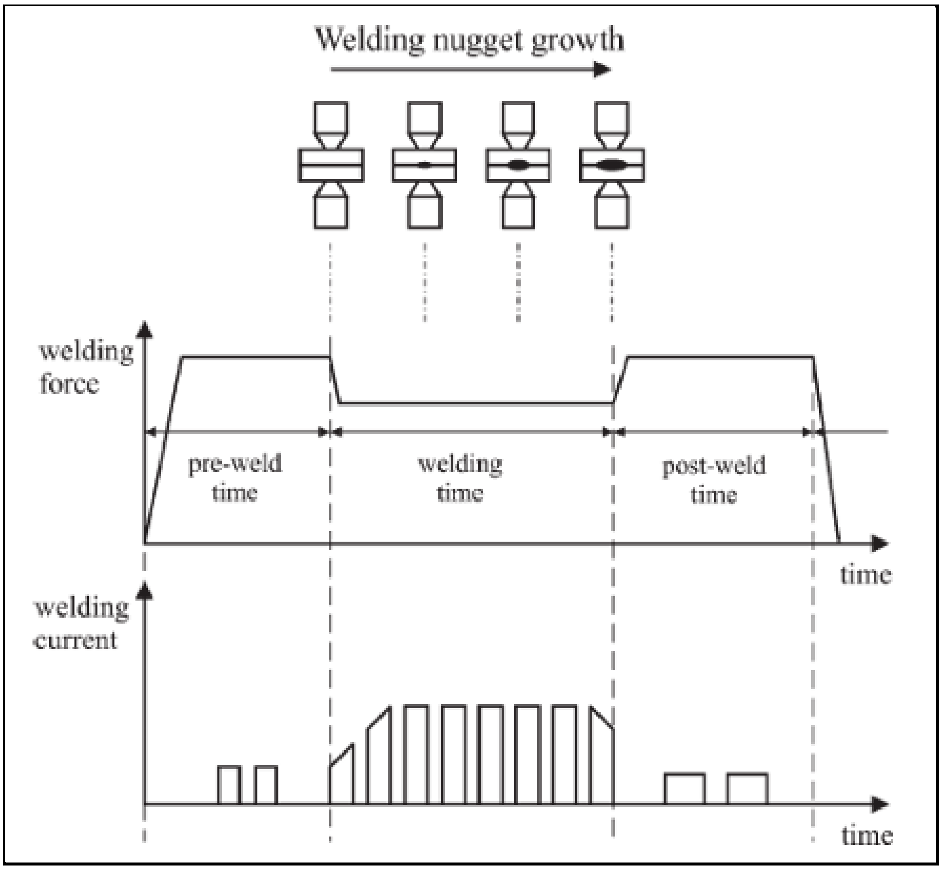


Figure 2. Growth of Welding Nugget Size Over Time

Source : Podržaj, (2008)

American Welding Society (AWS) D17.2

In the mid-1990s, the AWS D17 committee decided to create specifications for RSW. These specifications are used for aluminum, steel, and titanium alloys. AWS was developed in accordance with the American National Standard Institute (ANSI, 2019).

RESEARCH METHOD

This research employed a comparative quantitative method with a descriptive approach to evaluate the feasibility of resistance spot welding (RSW) on 2024-T42 aluminum alloy sheets. The methodology refers to the requirements and testing procedures outlined in the American Welding Society's AWS D17.2/D17.2M:2019, the tensile testing standard ASTM International ASTM E8, and the macrographic examination standard ASTM E340. The welding process was conducted using a single-phase AC resistance spot welding machine with a maximum current capacity of 35 kA, electrode tip diameter of 6 mm, and water-cooled copper alloy electrodes.

Prior to welding, all specimens were cleaned mechanically and chemically to ensure surface resistance values were below 50 μΩ, as required by AWS D17.2. The tensile shear test was conducted on three welded specimens with dimensions of 100 × 19.5 × 0.65 mm using a universal testing machine with a crosshead speed of 2 mm/min. Macrographic examinations were performed on three additional specimens, etched with Keller's reagent, and analyzed using a stereomicroscope to measure nugget penetration and indentation.

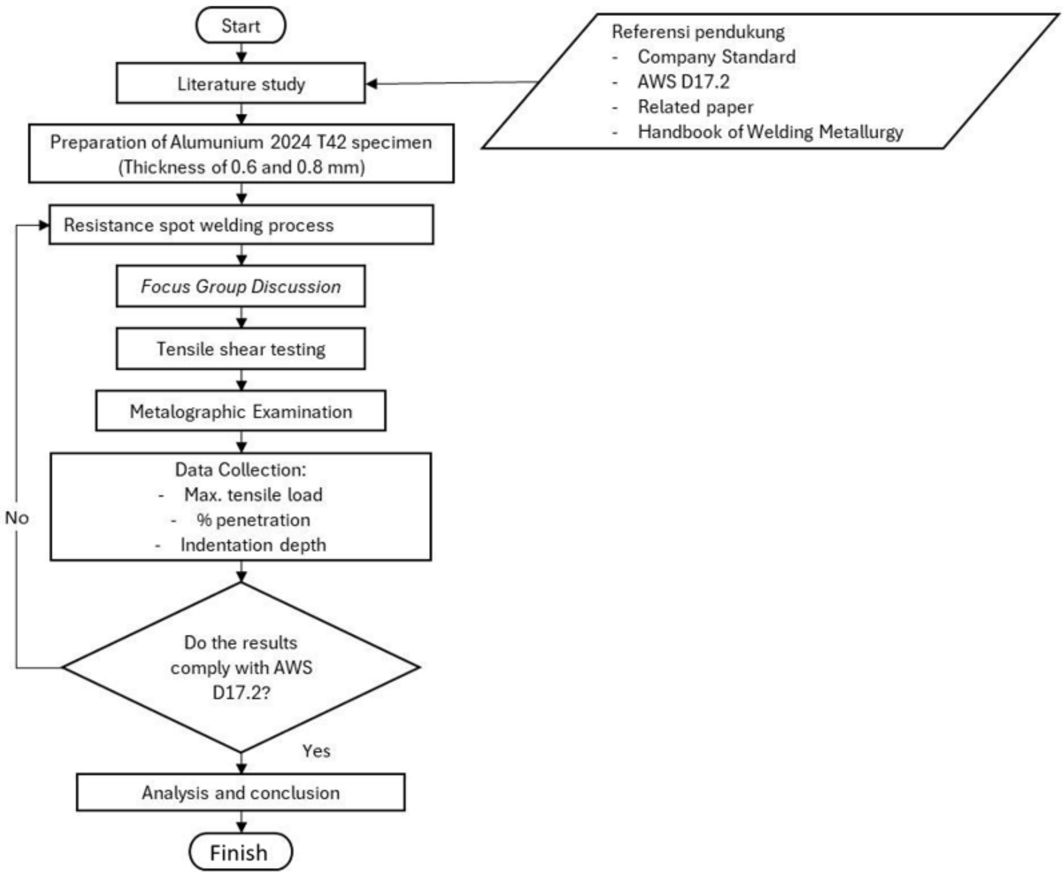


Figure 3. Research Flowchart

The author studied the AWS D17.2 standard through research and discussion, then observed the RSW machine and the pre-welding process to ensure the accuracy of the data. Subsequently, aluminium 2024 T42 samples (three for macrographic testing and three for tensile shear testing) were produced by a licensed operator. The samples were then tested in a metallurgical laboratory using tensile shear and macrographic methods. The test results were compared with the AWS D17.2 standard.

FINDINGS AND DISCUSSION

Based on macroscopic testing, tensile shear, and pre-welding processes (including post-cleaning), the data are presented in Table 1.

Table 1. Results of the RSW process testing data

Sample	Testing	Dimension (length x width x thickness)	Surface Resilience	Percentage of Penetration	Indentation mm	Maximum Load
Raw Material	Tensile Shear Test	- 12.65 mm 3.184 mm	-	-	-	461.54 Mpa
Tensile Shear (a,b,c)	Tensile Shear Test	(a,b,c) 100 mm 19.5 mm 0.65 mm	-	-	-	(a) 337.95 lbf (b) 329.16 lbf (c) 287.56 lbf
Post Cleaning	Resistance Test	-	8, 10, 9, 8, and 12	-	-	-
Macrography L	Macrography Test	- - 0.65 mm	-	Max 55% Min 50%	(0.6) 0.05 (0.8) 0.04	-
Macrography T1	Macrography Test	- - 0.66 mm	-	Max 51.72% Min 50%	(0.6) 0.08 (0.8) 0.06	-
Macrography T2	Macrography Test	- - 0.66 mm	-	Max 55% Min 45%	(0.6) 0.06 (0.8) 0.03	-

The results of the research that has been conducted also define that the material aluminum 2024 T42 belongs to Group 1 and Class B. The definitions of the preproduction process and routine tests in the specification document AWS D17.2 are also defined within that document. The definitions can be observed in Figures 7 and 8 below.

1.1.1 Material Groups

Group 1—Aluminum and magnesium

Group 2—Steel, nickel, and cobalt

Group 3—Titanium

1.1.2 Classification. Classification is based on the following:

Class A—A welded joint, whose failure during any operating condition would cause loss of the equipment or system or one of its major components.

Class B—A welded joint whose failure would reduce the overall strength of the equipment or system or limit the intended functioning or use of equipment.

Class C—A welded joint for which no stress analysis is required and whose failure would not affect the performance of the equipment or system.

Figure 7. Definition of group and class
Source: ANSI, (2019)

5.2.1 Test Lots. Test lots of witness specimens for production parts shall be as noted below.

Each test lot shall consist of the number and configuration of test specimens and method of evaluation as specified in Table 13 and 4.8.3.5(3). Any of the quantities specified may be made on a simulation of the production joint or a production part.

(1) *Preproduction Lot.* At the start of each work day or before a new production lot is welded, whichever comes first, or before welding is resumed after a machine shutdown.

(2) *Routine Lot.* At intervals specified in 5.2.2.1 or 5.2.2.2 during production welding and after an electrode change, or other minor welding equipment change.

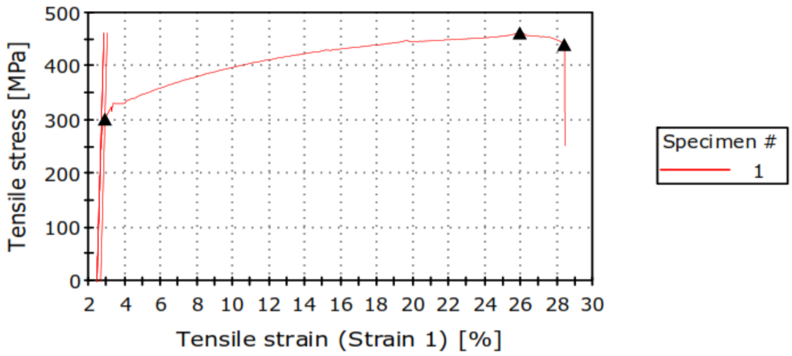
Figure 8. Definition of preproduction and routine lot
Source: ANSI, (2019)

The purpose of the test lots is to ensure the uniformity of the RSW process. In addition, it is also to maintain the consistency of welding results and the durability of the RSW machine. Based on the Class B classification for the routine lot limitation, it must be below a 2-hour interval while the RSW machine is in use. This standard is provided because there is no guarantee that the RSW machine will produce the same quality results beyond two hours of operation. Moving on to the next process, which is the observation of the RSW machine and the pre-welding process. At this stage, surface preparation is needed (see Figures 4 and 6). The aim of this preparation is to achieve a surface resistance value that meets the AWS D17.2 standards.

5.1.4 Surface Resistance. A daily check shall be made of the surface resistance in micro-ohms for Group 1 (Class A) welds when running production parts. A minimum of five readings shall be made on samples typical of the material being welded and its surface condition and preparation. The details of the method of obtaining the surface resistance measurement shall be the same as those used for the certification of welding schedules or cleaning procedures and the values of the surface resistance shall not exceed the limits of consistency and maximum values established at that time.

Figure 9. Definition of surface resistance
Source: ANSI, (2019)

Based on the test results, the surface resistance values obtained were 8, 10, 9, 8, and 12 μΩ. According to other specifications, the surface resistance value should not exceed 50 μΩ. Therefore, based on the criteria outlined in Figure 9, the pre-welding preparation process shows acceptable values. Thus, the data that will be obtained in the following discussion is representative of the feasibility of the RSW machine. Furthermore, a welding process was carried out for 3 macrograph samples and 3 tensile test samples. This also adheres to the standard mentioned in AWS D17.2. In the previous tensile shear tests, the material must have strength data before welding is performed. This data is intended to determine the minimum standard classification according to AWS D17.2. The material values before welding are shown in Figure 10, while the tensile shear test results are presented in Figure 11. The standardization values, as per AWS D17.2, can be observed in Figures 12 and 13 for the dimensional standards of the welded sample.



Results table 1

	Width [mm]	Thickness [mm]	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile stress at Yield (Offset 0.2 %) [MPa]	% Strain at After Break	Modulus (Automatic Young's) [GPa]	Break Location
1	12.65	3.184	18589.84	461.54	301.60	14.20	120.732	A (Inside GL)

Figure 10. Tensile test result of welded Al 2024-T42 plates with a thickness combination of 0.6 + 0.8 mm

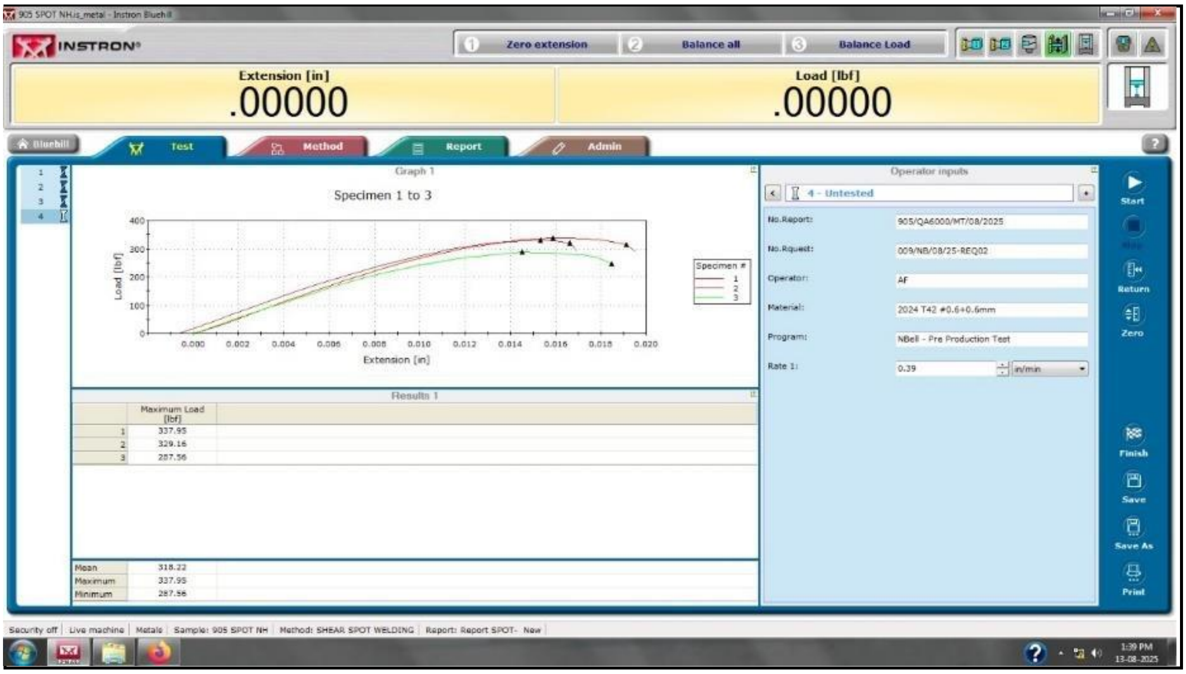


Figure 11. Tensile shear test result of welded Al 2024-T42 plates with a thickness combination of 0.6 + 0.8 mm

Table 1
Shear Load Requirements for Spot Weld Sheet Specimens
Group 1 Alloys—Aluminum and Magnesium Alloys

Nominal Thickness of Thinner Sheet		Ultimate Strength[a]				Ultimate Strength[a]				Ultimate Strength[a]				Ultimate Strength[a]			
		56 000 psi and above lbf per Spot Weld		386 MPa and above N[b] per Spot Weld		35 000 psi to 55 999 psi lbf per Spot Weld		240 MPa to 385.9 MPa N[b] per Spot Weld		19 500 psi to 34 999 psi lbf per Spot Weld		135 MPa to 239.9 Mpa N[b] per Spot Weld		Below 19 500 psi lbf per Spot Weld		Below 135 MPa N[b] per Spot Weld	
in	mm	min.	min. avg	min.	min. avg	min.	min. avg	min.	min. avg	min.	min. avg	min.	min. avg	min.	min. avg	min.	min. avg
0.010	0.25	60	75	265	335	50	65	225	290	—	—	—	—	—	—	—	—
0.012	0.30	75	95	335	425	65	85	290	380	30	40	135	175	20	25	90	110
0.016	0.40	110	140	490	625	100	125	445	555	70	90	310	400	50	65	225	290
0.018	0.45	125	160	555	710	115	145	510	645	85	110	380	490	65	85	290	380
0.020	0.50	140	175	625	780	135	170	600	755	100	125	445	555	80	100	355	445
0.022	0.55	160	200	710	890	155	195	690	865	120	150	535	665	95	120	425	535
0.025	0.65	185	235	825	1045	175	200	780	890	145	185	645	825	110	140	490	625
0.028	0.70	215	270	995	1200	205	260	910	1155	175	220	780	980	135	170	600	755
0.032	0.80	260	325	1155	1445	235	295	1045	1310	210	265	935	1180	165	210	735	935
0.036	0.90	305	385	1355	1710	275	345	1225	1535	255	320	1135	1425	195	245	865	1090
0.040	1.00	345	435	1535	1935	310	390	1380	1735	300	375	1335	1670	225	285	1000	1270

Figure 12. Maximum Standardization Value of AWS D17.2 Load
Source: ANSI, (2019)

Nominal Thickness of Thinner Sheet, in	W in, min.	Nominal Thickness of Thinner Sheet, mm	W mm, min.
Over 0.008 to 0.030	0.68	Over 0.20 to 0.75	17.0
Over 0.030 to 0.100	1.00	Over 0.75 to 2.50	25.0
Over 0.100 to 0.130	1.25	Over 2.50 to 3.20	32.0
Over 0.130	1.50	Over 3.20	38.0

Figure 13. Standardization value of the sample size results from RSW
Source: ANSI, (2019)

Based on the raw material testing values, the maximum load obtained is 461.54 MPa; thus, referring to Figure 12, the value of the ultimate strength table, which is 386 MPa or higher, is selected. Then, due to the minimum plate thickness of 0.65 mm, the row of the nominal thickness table for the minimum plate thickness of 0.65 mm is chosen. Accordingly, the minimum standard value for the tensile shear test is 185 lbf and the minimum average is 235 lbf. Furthermore, referring to the tensile shear test results, the maximum load values for the three samples are 337.95 lbf, 329.16 lbf, and 287.56 lbf, respectively, and the average value of the three samples is 318.22 lbf. Referring to Table 1, for a sample length value of 100 mm, with a thickness of 0.65 mm and a width of 19.5 mm. Meanwhile, the standardization (Figure 13) has a minimum width of 17 mm and a minimum length of four times the width of the sample, which is 68 mm, thus fulfilling the standards of AWS D17.2 in terms of dimensions and tensile strength. Next, for the standardization of production deviation (Figure 14) at point two, it is stated that the deviation range must be below 35%. Thus, the sample deviation values are a 19.73, sample b 10.94, sample c -30.66. Then, based on the CV (coefficient of variation) formula and the σ (standard deviation) formula, the CV value can be obtained as follows.

$$\sigma = \sqrt{\frac{\sum(xi-\mu)^2}{n-1}} = \sqrt{\frac{389.2729+119.6836+940.0356}{2}} = 26.9164$$

$$CV = \left(\frac{\sigma}{\mu}\right) X\ 100\% = \frac{26.9164}{318.22} \text{ X } 100\% = 8.458\ \%$$

Thus, a deviation value of 8.458% is obtained and does not exceed 35%. Therefore, from the deviation aspect, it is stated to meet the AWS D17.2 standards.

(2) *Production Witness Specimens.* The spread between the lowest and highest specimen shall be less than 35% of the applicable production test lot average.

Figure 14. Standard range of Tensile Test Values
Source: ANSI, (2019)

In the macrography test, a good nugget shape was obtained without any defects at all (Figure 15). Meanwhile, according to AWS D17.2, the standard defect limit is determined to be no more than 3% for penetration and size, and 6% for defects and cracks (Figure 16). Thus, it is declared that from a visual standpoint, it meets the criteria of AWS D17.2.

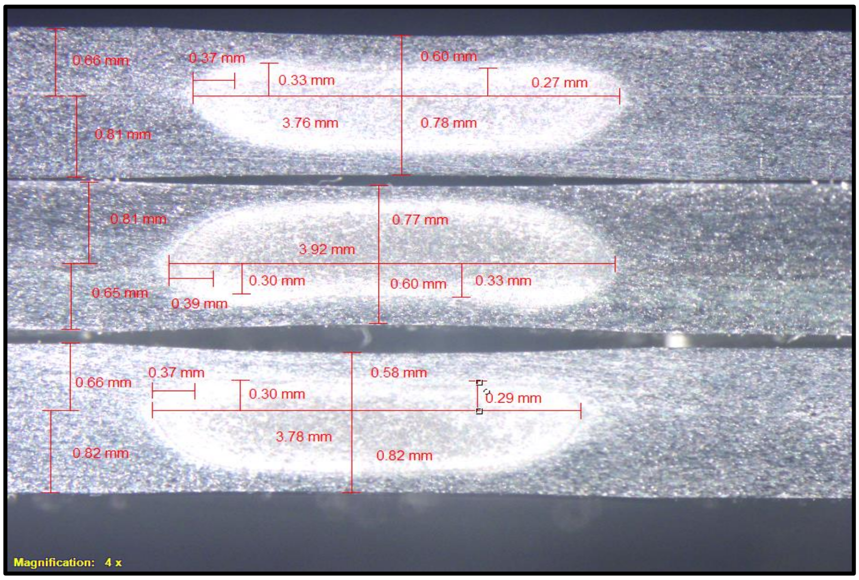


Figure 15. Results of The Macrography Test on Samples T2, L, and T1

Table 12
Internal Metallographic Imperfections for Production Witness Samples or Sectioned Parts

	Acceptable Percentage of Welds Exhibiting Imperfection		
Nature of Weld Imperfections	Class A	Class B	Class C
Porosity, Cracks, Incomplete-Fusion (4.8.3.1)	0%	6%	N/A
Insufficient Penetration [4.8.3.4(1)]	0%	3%	N/A
Excessive Penetration [4.8.3.4(2)]	0%	3%	N/A
Insufficient Size (4.8.3.5)	0%	3%	N/A

Figure 16. The limits of disability are viewed from the internal metallography
Source: ANSI, (2019)

Referring to the results of the macrography test (Table 1), the maximum and minimum penetration values obtained were 55% and 50%, while for the 0.6 mm plate, the indentation was 0.05 mm and for the 0.8 mm plate it was 0.04 mm on sample L (longitudinal). Then for samples T1 and T2 (transversal), the maximum and minimum penetration values were 51.72%, 50% and 55%, 45%, respectively. The indentation values were 0.08 mm for the 0.6 mm plate and 0 mm for the 0.8 mm plate, and 0.06 mm for the 0.6 mm plate and 0.03 mm for the 0.8 mm plate. These values were obtained from formulas referring to Figures 17 and 19. The penetration and indentation formulas are presented below.

$$P\ max\ = \frac{longest\ distance\ between\ side\ and\ center\ of\ the\ nugget}{length\ of\ the\ shortest\ side}\ X\ 100\%$$

$$Indentation\ = distance\ from\ the\ side - distance\ from\ the\ center\ side$$

$$P\ min\ = \frac{shortest\ distance\ between\ side\ and\ center\ of\ the\ nugget}{length\ of\ the\ shortest\ side}\ X\ 100\%$$

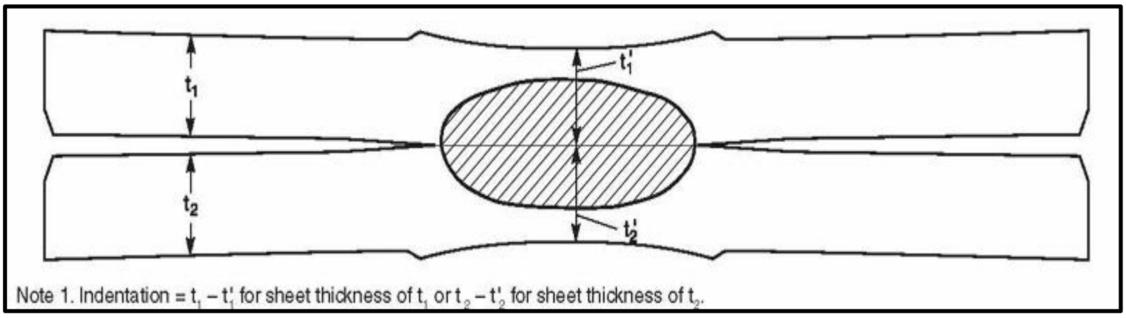


Figure 17. Macrography Indentation
Source: ANSI, (2019)

The next process is to cross-check with the AWS D17.2 standards presented in Figures 18 and 19. The indentation limit for Sheet Class B is shown at point two, which is 0.13 mm. However, from an aerodynamic perspective, it must be below 0.10 mm (point five). Aerodynamic considerations are generally only used for aircraft due to their high speeds. This indicates that the level of concavity affects the differences in wind pressure when passing through the RSW welding area, impacting the structural strength of the components as well as fuel efficiency. However, the macroscopic test results show that it meets aerodynamic aspects. The penetration limits are divided into two, namely a minimum penetration of 20% and a maximum penetration of 80%. This penetration affects the structural strength value, where a larger nugget size means greater strength. However, if it is too large, it can cause defects. Therefore, based on the indentation and penetration values obtained, the results are deemed acceptable and meet the AWS D17.2 criteria.

4.8.1.4 Surface Indentation. Indentations (see Figure 8) are not acceptable if their depth exceeds the following limitations (where t is the thickness of the indented outer member). Excessive indentation is not acceptable on test specimens. Excessive indentation of welds sampled shall not exceed 3% of measured welds for Class A or 10% for Class B and C of production parts or lots. Locally displaced material, if present, resulting in a ridge around the periphery of weld shall not be included in determining indentation.

(1) **Sheet; Class A and B:** 10% t or 0.005 in [0.13 mm]; whichever is greater.

(2) **Sheet; Class C:** 20% t or 0.005 in [0.13 mm]; whichever is greater

(3) **Foil; Class A:** 30% t

(4) **Foil; Class C:** 40% t

(5) When aerodynamic smoothness is a requirement, the indentation shall not exceed 0.004 in [0.10 mm] on sheet and 20% of foil thickness.

Figure 18. Indentation Standard
Source: ANSI, (2019)

4.8.3.4 Penetration. At least 80% of the measured nugget diameter shall exceed the minimum penetration requirement (see Figure 10). Maximum penetration shall be measured at the maximum extent into each outer sheet using thickness at the indented area. See Annex D for proposed method of measuring seam welds.

(1) *Minimum Penetration.* Penetration shall comply with the following:

(a) In two equal-thickness members, penetration shall exceed 0.2 times the thickness of each member into each member.

(b) In two unequal-thickness members, penetration shall exceed 0.2 times the thickness of the thinner member into each member.

(c) In three or more thicknesses, penetration into the outer members shall exceed 0.2 times the thickness of the thinner outer member into each outer member.

(2) *Maximum Penetration.* Penetration shall not exceed:

(a) *Group 1 Materials.* 80% for Class A and Class B welds, 90% for Class C welds.

(b) *Group 2 and 3 Materials.* 90% for all classes.

Figure 19. Penetration Standard
Source: ANSI, (2019)

The results obtained from tensile shear testing showed average maximum loads of 318.22 lbf, exceeding the minimum requirement of 235 lbf as stipulated in AWS D17.2 for Class B thin-sheet aluminium joints. The macrographic examination revealed penetration depths ranging from 45% to 55% and indentation values below 0.10 mm, which also comply with the acceptance criteria.

To validate these findings, the results were compared with those of previous studies on the resistance spot welding of 2xxx-series aluminium alloys. Haghshenas (2019) reported an average tensile shear strength of approximately 290 lbf for Al 2024-T3 sheets with a thickness of 0.8 mm under similar welding conditions. Similarly, Koesgi (2021) found that the tensile shear strength of Al 2024 joints was achieved at 300–310 lbf for sheet combinations of 0.6 + 0.6 mm. Compared to these studies, the present work demonstrates a slightly higher tensile shear strength (318.22 lbf), indicating a stable weld nugget formation despite the use of dissimilar sheet thicknesses (0.6 + 0.8 mm).

Furthermore, the penetration and indentation values measured in this study fall within the range of 45–55% and <0.10 mm, respectively, which are in line with the findings of Podržaj (2008) and Hendaryati (2022), who reported penetration values between 40–60% for acceptable aerospace welds. This confirms the consistency of the welding process and its compliance with the acceptance criteria outlined in AWS D17.2.

Unlike most previous studies that investigated equal-thickness joints (e.g., 0.6 + 0.6 mm or 0.8 + 0.8 mm), this research evaluates the feasibility of RSW for dissimilar sheet thicknesses (0.6 mm + 0.8 mm) of Al 2024-T42 alloy. This thickness combination is widely used in helicopter and aircraft skin structures, where weight reduction and structural integrity must be balanced. The results demonstrate that the RSW process can still achieve mechanical properties that meet the minimum requirements for aerospace applications, thereby validating its suitability for use in thin-gauge structural components.

These findings strengthen the argument that RSW is a technically feasible and reliable joining method for dissimilar thin aluminium sheets in the aerospace industry. Future studies may include fatigue and corrosion tests to evaluate long-term performance further. These results are consistent with other recent studies on aluminium RSW, which also achieved acceptable penetration and strength under similar thickness conditions (Rahimi, 2020; Epperlein, 2024)

Thus, it is stated that the RSW machine is suitable for welding components of the N Bell helicopter. The components that are typically welded are the Duct Assy, with an AISI 321 material combination of 0.5 + 0.5, the Skin Assy, with aluminium 2024 T42 material combination of 0.6 + 0.6, and the Door Assy, with aluminium 2024 T42 material combination of 0.6 + 0.8. Then, to facilitate the results of the machine's feasibility, Table 2 is provided.

Table 2. Test results data of the RSW machine feasibility

Sample	Testing	Dimension (length x width x thickness)	Test Results	Acceptance Criteria	Description
Tensile Shear Rate	Tensile Shear Test	100 mm 19.5 mm 0.65 mm	318.22 lbf	235 lbf	PASS
Tensile Shear (a,b,c)	Tensile Shear Test	100 mm 19.5 mm 0.65 mm	(a) 337.95 lbf (b) 329.16 lbf (c) 287.56 lbf	185 lbf	PASS
Pasca Cleaning	Resistance Test	-	8, 10, 9, 8, dan 12	≤50	PASS
Macrography L	Macrography Test	- - 0.65 mm	Max 55% Min 50%	20% - 80%	PASS
Macrography T1	Macrography Test	- - 0.66 mm	Max 51.72% Min 50%	20% - 80%	PASS
Macrography T2	Macrography Test	- - 0.66 mm	Max 55% Min 45%	20% - 80%	PASS
Macrography L	Macrography Test	- - 0.65 mm	0.05 mm dan 0.04 mm	0.13 mm	PASS
Macrography T1	Macrography Test	- - 0.66 mm	0.08 mm dan 0 mm	0.13 mm	PASS
Macrography T2	Macrography Test	- - 0.66 mm	0.06 mm dan 0.03 mm	0.13 mm	PASS

CONCLUSIONS

Based on the research that has been conducted, the author reaches the following conclusions:

1. The tensile shear test results of 337.95 lbf, 329.16 lbf, and 287.56 lbf with an average of 318.22 lbf exceeded the minimum requirements of AWS D17.2 (185 lbf minimum and 235 lbf average). This indicates that the RSW process on Al 2024-T42 with dissimilar sheet thickness (0.6 mm + 0.8 mm) can produce joints that meet aerospace structural standards.
2. Macrographic examination showed penetration values of 45–55% and indentation values below 0.10 mm. These results are within the acceptance criteria of AWS D17.2, including aerodynamic considerations for thin-skin aircraft structures.

3. Compared to previous studies, this study demonstrated equal or better joint performance without specialized electrodes, supporting the use of RSW for lightweight aircraft structures. The findings provide both practical insights for manufacturing and theoretical data for future studies.

LIMITATIONS & FURTHER RESEARCH

This study focused solely on tensile shear testing and macrographic examination of RSW joints on Al 2024-T42 with sheet thicknesses of 0.6 mm and 0.8 mm. Other important properties, such as fatigue, fracture toughness, and corrosion resistance, were not evaluated. The welding process was also limited to a single set of parameters and flat sheet specimens. Future studies should include parameter optimization, fatigue and corrosion tests, and application on fundamental aircraft components to provide a more complete understanding of joint performance.

REFERENCES

American National Standards Institute. (2019). *Specification for resistance welding for aerospace applications (AWS D17.2/D17.2M:2019).* American Welding Society.

Bakhori, A. (2017). Perbaikan metode pengelasan SMAW (*shield metal arc welding*) pada industri kecil di Kota Medan. *Buletin Utama Teknik, 13*(1), 14–21. https://doi.org/10.30743/but.v13i1.255

Dada, M., & Popoola, P. (2024). Recent advances in joining technologies of aluminum alloys. *Discover Materials, 4,*86. https://doi.org/10.1007/s43939-024-00155-w

Dursun, T., & Soutis, C. (2014). Recent developments in advanced aircraft aluminum alloys. *Materials & Design, 56,*862–871. https://doi.org/10.1016/j.matdes.2013.12.002

Epperlein, M., Schiebahn, A., & Reisgen, U. (2024). Resistance spot welding of die-cast and wrought aluminum alloys: Improving weld spot quality through parameter optimization. *Welding in the World, 69*(2), 531–553. https://doi.org/10.1007/s40194-024-01901-7

Haghshenas, N., & Moshayedi, H. (2019). Monitoring of resistance spot welding process. *Experimental Techniques, 43*(6), 685–696. https://doi.org/10.1007/s40799-019-00341-z

Hendaryati, H., Wibowo, A., Kurniawan, R., & Setiawan, B. (2022). Pengaruh variasi ketebalan plat aluminum 2024 T42 terhadap kekuatan tarik dan *macrography* pada proses resistance spot welding. *JTTM: Jurnal Terapan Teknik Mesin, 3*(2), 96–107. https://doi.org/10.37373/jttm.v3i2.299

Khan, M. I. (2007). *Welding science and technology.* New Age International Publishers. (Accessed September 2, 2025).

Koesgi, D. P., Sehono, S., & Wicaksono, D. (2021). Pengaruh pemanasan awal terhadap sifat mekanik sambungan spot friction stir welding dalam pemasangan *rivet* aluminum 2024. *Teknika STTKD: Jurnal Teknik, Elektronik, Engine, 7*(1), 140–153. https://doi.org/10.56521/teknika.v7i1.315

Mazzolani, F. M. (1995). *Aluminum alloy structures* (2nd ed.). E & FN Spon. (Accessed September 3, 2025).

Podržaj, P., Kosec, B., & Kosec, L. (2008). Overview of resistance spot welding control. *Science and Technology of Welding and Joining, 13*(6), 523–532. https://doi.org/10.1179/174329308X283893

Priyotomo, G., Astawa, I. N. G. P., & Rokhmanto, F. (2021). Efek perlakuan panas terhadap sifat mekanik logam stainless steel seri J4. *TEKNIK, 42*(2), 117–122. https://doi.org/10.14710/teknik.v42i2.36461

Rahimi, S., Liu, H., Ghassemi-Armaki, H., & Fukumoto, S. (2020). Resistance spot welding of aluminum to aluminum clad. *Journal of Manufacturing Processes, 56,* 798–805. https://doi.org/10.1016/j.jmapro.2020.04.035

Sahrevy, M. A., Mawardi, & Dailami. (2021). Analisa pengaruh kuat arus dan waktu las pada proses las titik (*resistance spot welding*) terhadap kekuatan tarik pada hasil sambungan las pelat SS 400. *Jurnal Mesin Sains Terapan, 5*(2), 41–48. https://doi.org/10.30811/jmst.v5i2.2411

Wibawa, L. A. N. (2019). Pengaruh pemilihan material terhadap kekuatan rangka *main landing gear* untuk pesawat UAV. *Jurnal Teknologi dan Terapan Bisnis (JTTB), 2*(1), 48–52. https://doi.org/10.0301/jttb.v2i1.60

Wiryosumarto, H., & Okumura, T. (2000). *Welding Technology of Metals* (8th ed.). Jakarta: PT Pradnya Paramita. ISBN 979-408-175-2.