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Experimental Study of Spot Welding Current Variation on SUS 304 and DIN 1.4003 Materials

Alfi Tranggono Agus Salim[1], Nanang Romandoni[2], Wida Yuliar Rezika[3], Indarto Yuwono[4], Akbareza Urbaningrum[5], Ni Jade Salsabiila[6], Denisa Eka Febrianti[7], Halimatus Sa'diyah[8]
[1,3,4,5,6,7,8]Rollingstock Engineering, Depertement of Engineering, State Polytechnic of Madiun, Indonesia
[2] Automotive Mechanical Engineering, Depertement of Engineering, State Polytechnic of Madiun, Indonesia

Abstract— *Resistance Spot Welding or electric resistance spot welding is a resistance welding method used to join plates or thin materials with the pressure of electrically conducting electrodes. The research problem is that different combinations of materials with varying thicknesses affect the welding results. The research objective is to investigate the influence of spot welding current variations on the combination of materials, such as SUS 304 with DIN 1.4003 and SUS 304 with SUS 304, on shear strength, nugget diameter, and the resulting microstructure. The research results show that variations in welding current affect the welding quality of the used material combinations. In dissimilar material combinations, the nugget diameter and shear stress strength increase as the welding current increases. The same applies to similar material combinations, where the nugget diameter and shear stress strength also increase with the increase in welding current. The welding current that produces the highest nugget diameter and shear stress strength in dissimilar material combinations is 10kA, with a nugget diameter of 7.17 mm and shear stress strength of 413.625 N/mm2. On the other hand, in a similar material combination, the highest welding current of 12kA results in a nugget diameter of 7.5 mm and shear stress strength of 278 N/mm2. Micro evaluation results indicate that variations in welding current affect the melting in the nugget area. The microstructure formed in the nugget area consists of the respective parent metals in each combination, and there is also martensite and dendritic structure due to the rapid cooling rate from welding.*

Keywords— *Resistance Spot Welding; weld current; SUS 304; DIN 1.4003; weld quality.*

I. INTRODUCTION

The spot welding process is used to join materials in the form of sheets/plates by attaching the surfaces of the materials and then pressing them together using electrodes supplied with electric current, causing the metal to melt due to electrical resistance [1]. Spot welding or Resistance Spot Welding is commonly used in the assembly process of vehicle bodies, where thin sheets are also frequently used. The materials commonly used for vehicle body construction are stainless steel sheets[2].

The types of stainless steel commonly used in the transportation industry are SUS 304 and DIN 1.4003. Both combinations of these stainless steel materials are joined using a spot welding process. In industrial applications where different combinations of materials are used, welding parameters may not be optimal, thus requiring a trial stage in determining the parameters for each combination of materials [3].

According to the research by Haikal and Triyono (2013), different thicknesses in similar materials, dissimilar materials with the same thickness, or a combination of both affect the welding result, precisely the nugget diameter [4]. In addition to the material type and thickness, the welding parameter, the welding current, was the most influential factor in the nugget diameter produced by the spot welding process [5].

This research was conducted to investigate the influence of various welding current variations on stainless steel specimens of SUS 304 with DIN 1.4003 and SUS 304 with SUS 304 after spot welding on the quality of the welding results and welding distortion. Both materials are developed by PT INKA for the E-Bus G20 8M project, specifically for the sidewall (frame) section, using the Spot Welding method for the joining process.

II. THEORETICAL REVIEW

The theoretical review contains the knowledge related to the research object that the researcher uses as a reference in conducting the study.

A. Resistance Spot Welding

Resistance Spot Welding is a welding method used to join plates by applying pressure from electrically conducting electrodes. Electric current flows between the two electrodes through the clamped metal, generating heat that melts and connects the metals [1]. The result of Spot Welding may have potential distortion effects caused by the welding process, such as:

- Mechanical Distortion is in the form of bending due to electrode pressure on the material surface.
- Thermal Distortion is distortion on the material caused by inaccuracies in the Spot Welding process parameters.
- Gross Distortion is distortion on the welded material due to ill-fitting materials being forced to merge [6].

Factors influencing the results of Spot Welding include the type of materials, the alloy type, welding current and speed, welding equipment, and the electrodes used [6].

B. Spot Welding Parameter

To achieve optimal welding results, the parameters to be considered in the welding process are as follows:

- Welding Current (Weld Current), the amount of heat generated depends on the welding current, which affects the diameter of the welding result (nugget) [7].
- Electrical Resistance (Resistance), electrical resistance influences the formation of the welding nugget according to the resistance level [8].

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- Welding Time (Weld Time), the amount of input energy in the weld depends on the welding time because shorter welding time results in less heat being transferred to the workpiece.

C. Stainless Steel

Stainless steel is a type of steel known for its corrosion resistance characteristics. It is classified as stainless steel because it contains a minimum of 10.5% chromium in its chemical composition [9].

D. Tension Shear

Tension Shear or Tensile Shear Test is a test used to determine the strength of welds. This test occurs when an object is subjected to two opposing forces perpendicular to the axis of the rod and not in line with the rod provided [10]. Tensile tests were also conducted to determine the strength of the welding results and material properties [11].

E. Macro Sectional Test

Macro Sectional Test is conducted on a transverse cross-section. This test is used to inspect the size of the weld, examine fracture surfaces, and indicate internal discontinuities [12]. The Macro Sectional Test is performed by visual inspection and utilizes tools such as a microscope or magnifying loop to determine the nugget shape, nugget diameter, average penetration, and internal defects after cutting at several points along the vertical indication [13].

F. Micro Examination

Micro Examination, or microstructural analysis, serves to determine the structure of materials, predict material properties, design alloys with new combinations of properties, and determine proper heat treatments [14]. Micro examination is carried out by observing the structure in the welding joint area using a microscope, provided that the test specimen has been etched. The results of observations in the form of structures on the base metal, weld metal, HAZ boundaries, layers and welding results [15].

III. RESEARCH METHOD

The research methodology includes information about the research stages to achieve the research objectives, as follows:

A. Equipment and Materials

In the research, several pieces of equipment and materials used are:

TABLE I. Equipment and Materials

Equipment	Materials
Spot Welding Machine	SUS 304 Material with 1 mm Thickness
Macro Sectional Test Machine	DIN 1.4003 Material with 2 mm Thickness
Microscope Digital Series Olympus	Cutting Disc (Micro Cutting)
Tensile Test Machine	Polishing Paper
Gap Shear Machine	Polishing Cloth
Polishing Machine	Mounting Resin
Ruler	Etching Reagent
Helmet	Autosol Paste
Safety Glasses and Gloves	Cloth/Tissue

B. Material Cutting

The materials used in this research are austenitic and ferritic stainless steel with types SUS 304 and DIN 1.4003. The material cutting is performed using a gap shear machine can be seen in Fig.1.

Fig. 1. Process Cutting Materials with Gap Shear Machine

Seen in Fig. 2, the results of cutting the material with size specifications referring to the JRS standard.

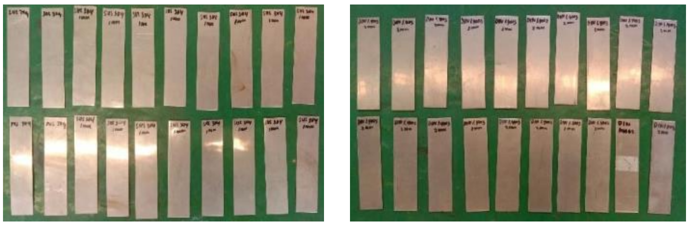

Fig. 2. Cutting Result

C. Welding Process

In this process, two combinations of materials are welded, namely the combination of SUS 304 with DIN 1.4003 and SUS 304 with SUS 304, using the Resistance Spot Welding method. The variations in the welded material combinations are done with the following welding current parameters:

TABLE II. Welding Current Parameters

Current Variations SUS 304 vs DIN 1.4003 (A)	Current Variations SUS 304 vs SUS 304 (A)
8.000	10.000
8.500	
9.000	
9.500	12.000
10.000	

D. Tensile Shear Test

Tensile testing is used to determine the shear stress value of the Spot Welding results on the welded material combinations. The value obtained from the testing is the Peak Load, which gives the shear stress value of the test material. The testing is conducted following the JRS (Japanese Railways Standard) standard. The tensile shear test can be seen in Fig. 3.

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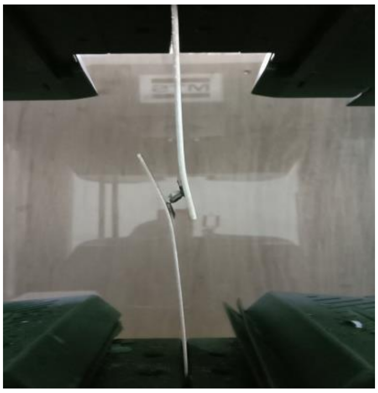


Fig. 3. The Process of Tensile Shear Test

E. Macro Sectional Test

Macro sectional testing is used to measure the nugget diameter of the welding result, penetration depth, and welding quality [16]. The testing is conducted using a Macro Microscope Digital with magnification ranging from 50 to 500 times. The macro sectional test can be seen in Fig. 4.

Fig. 4. The Process of Macro Sectional Test

F. Microstructure Examination

Micro examination testing is used to determine the microstructure of the welding results from two variations of welded materials[17]. Microstructure testing of specimens using an olympus BX53M microscope is carried out to observe the shape of the microstructure that occurs in the weld metal, HAZ, and base metal areas[18] . The microstructure examination can be seen in Fig. 5.

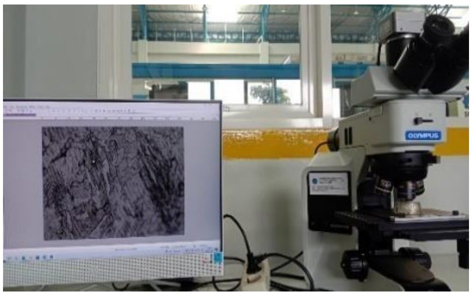


Fig. 5. The Process of Microstructure Examination

IV. Discussion

A. Macro Examination

Macro evaluation is conducted to measure the diameter of the nugget formed and observe the welding penetration for each variation of material combination in relation to the welding current.

- Combination of materials SUS 304 and DIN 1.4003

TABLE III. Macro Examination Results on Combination of Materials SUS 304 and DIN 1.4003

No	Welding Current Variation (A)	Nugget Diameter (mm)
1.	8.000	5,53
2.	8.500	5,90
3.	9.000	6,08
4.	9.500	6,62
5.	10.000	7,17

The measurement results show that the nugget diameter increases as the welding current increases. According to Zhang and Senkara's theory, the welding current affects the heat input rate, leading to higher heat input and affecting the nugget formation [10]. This study shows that increasing the welding current affects the nugget diameter, making it larger or increasing. This is influenced by the increasing heat input rate as the welding current used becomes higher. The larger nugget diameter with a higher welding current is a result of the increasing heat input and the higher welding current used [19].

- Combination of materials SUS 304 and SUS 304

TABLE IV. Macro Examination Results on Combination of Materials SUS 304 and SUS 304

No	Welding Current Variation (A)	Nugget Diameter (mm)
1.	10.000	5,4
2.	12.000	7,5

The combination of materials used, SUS 304 with SUS 304, in Spot Welding with welding current variations of 10k and 12k Amperes resulted in higher nugget diameters. The influence of heat input is the reason for the increase in the welding current, leading to larger nugget diameters. The use of materials with the same type does not affect the nugget result significantly, but the welding current in the welding process has a more significant impact on the formation of the nugget diameter in Spot Welding [5].

B. Tensile Shear Test

A tensile shear test is conducted to determine the microstructure formed in each variation of material combination concerned with the welding current.

- Combination of materials SUS 304 and DIN 1.4003

TABLE V. Tensile Shear Test Results on Combination of Materials SUS 304 and DIN 1.4003

No.	Welding Current Variation (A)	Peak Load (kN)	Shear Strength (N/mm^2)
1	8.000	10,773	395,179
2	8.500	11,251	406,619
3	9.000	11,902	408,414
4	9.500	12,183	412,609
5	10.000	12,429	413,625

The variation of welding current on dissimilar material combinations affects the peak load values obtained. As shown in Table V, the higher the welding current used, the higher the peak load values achieved. The increase in peak load values, which affects the shear strength, is attributed to the larger nugget diameter formed as the welding current variation increases[20]. Similar to the findings of Agustriyana and Irawan's study, high welding currents cause the material to melt and form wider nuggets, leading to an increase in the strength of the weld joint [21]. This research indicates that the shear strength increases as the welding current used increases, influenced by the larger nugget size as the welding current increases.

- Combination of materials SUS 304 and SUS 304

TABLE VI. Tensile Shear Test Results on Combination of Materials SUS 304 and SUS 304

No.	Welding Current Variation (A)	Peak Load (kN)	Shear Strength (N/mm^2)
1	10.000	13,307	278
2	12.000	12,275	159

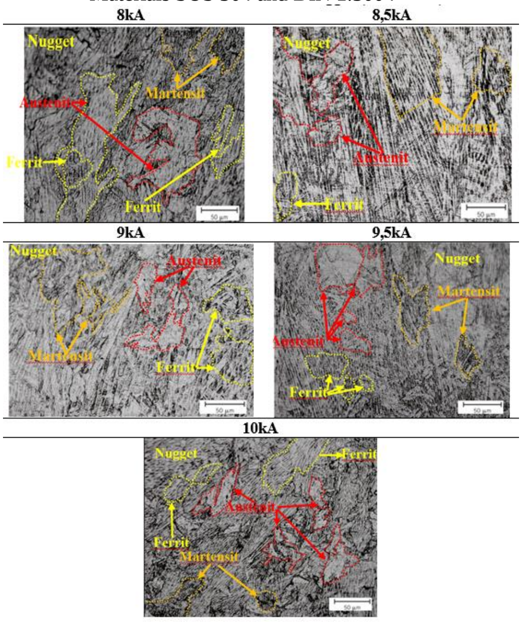
The variation of welding current on similar material combinations affects the peak load and shear stress results because effect of heat input [22]. Table VI shows that the higher the welding current used, the lower the peak load and shear stress values obtained.

C. Microstructure Examination

The microstructure examination is conducted to determine the microstructure formed in the nugget, heat-affected zone, and base metal for each variation of material combination with respect to the welding current.

- Combination of materials SUS 304 and DIN 1.4003

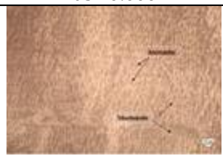
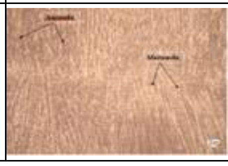
TABLE VII. Microstructure Examination Results on Combination of Materials SUS 304 and DIN 1.3004



Based on the micro evaluation results, it can be observed that in each welding current variation, the nugget area forms microstructures of austenite, ferrite, and martensite. The austenite and ferrite microstructures are formed from the crystallization of the parent metals, resulting in dominant austenite and ferrite microstructures in the weld zone due to the perfect melting of both material combinations [23]. This is supported by Bianto's research (2022), which states that the nugget forms microstructures from the parent metals that have melted completely [16]. In the nugget area, a martensite structure is also formed within the austenite microstructure due to the higher welding current leading to higher heat input, causing the austenite microstructure to transform into martensite [10].

- Combination of materials SUS 304 and SUS 304

TABLE VIII. Microstructure Examination Results on Combination of Materials SUS 304 and SUS 304

Arus 10.000 A	Arus 12.000 A
	

Based on the micro evaluation results in the nugget area for the combination of SUS 304 with SUS 304 materials, there are microstructures of austenite and martensite formed from the crystallization of the parent metals [19]. Austenite microstructure is characterized by a face-centered cubic (fcc) crystal structure, while micro martensite is characterized by a dendritic structure that elongates due to a rapid cooling rate after the welding process [24].

V. CONCLUSION

Variations in welding current (weld current) affect the size of the formed nugget diameter; the higher the welding current used, the larger the nugget diameter formed. This is influenced by the higher heat input rate as the welding current increases. The nugget diameter determines the connection between material combinations, affecting the welding strength. Therefore, the larger the nugget diameter resulting from welding current variations, the higher the shear stress strength as the welding current increases. In addition to influencing the nugget diameter and shear stress strength, welding current also affects the microstructure formed in the nugget area, resulting in austenite, ferrite, and martensite microstructures. In each welding current variation, the microstructure with the highest percentage is ferrite. As the welding current increases, the ferrite microstructure decreases, and the austenite microstructure increases. This is due to the high heat input from the welding current used.

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