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MICROSTRUCTURE ANALYSIS OF WELDING RESULTS *RESISTANCE BUTT WELDING* SPRING STEEL WIRE JIS G 3521

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Abstract (English)

This research analyses the microstructure changes in JIS G 3521 spring steel wire welded using resistance butt welding. The results show significant changes in the weld zone and heat-affected zone (HAZ), including the formation of new phases and changes in grain size. These changes are correlated with mechanical properties such as hardness and tensile strength. This study aims to understand the influence of welding parameters on microstructure and mechanical properties, as well as contribute to the development of optimal welding techniques.

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Key Words

Wheel Holder Ornament, Resistance Butt Welding, Micro Structure

1. Introduction

The automotive industry, particularly the assembly of *Wheel Holder Ornament* Toyota Fortuner, faces challenges in the welding process. Although the demand for local *butt welding* is increasing, quality, cost, delivery and quick response are still major concerns. Toyota seeks to address these issues through local projects and technology transfer, which drives the need for in-depth research to improve the welding process.

Figure 1.1 Wheel Holder Ornament

Wheel holder ornament is an important component in a car, which serves for aesthetics and structural safety. In the design of the Toyota Fortuner, this component is made of plastic that is attached to the wheel. To increase the strength and resistance to vibration and load, wire welding is performed. Previous research on optimising *resistance butt welding* on JIS G 3521 steel wire has been conducted, but the focus was more on mechanical properties such as tensile strength and optimal wire diameter. This research will analyse the microstructure *of resistance butt welding* on JIS G 3521 steel wire, because microstructure has a significant effect on the mechanical properties of the material.

In this test, the microstructure has a significant influence on the mechanical properties of this material. Therefore, this study aims to determine the quality of microstructure and mechanical properties. By conducting in-depth analysis of the microstructure *of resistance butt welding* results on JIS G 3521 steel wire to determine the mechanical properties and elements contained in JIS G 3521 carbon steel wire material.

To provide maximum results on the *ornament holder*. wire welding on plastic deflection on the Toyota Fortuner *ornament wheel holder*. Thus, it is hoped that the results of this study can provide valuable insight in determining the microstructure results at the optimal diameter of wire welding results to ensure the strength and durability of the *wheel holder ornament*, so as to increase durability and driving comfort for users of these vehicles.

2. Methods

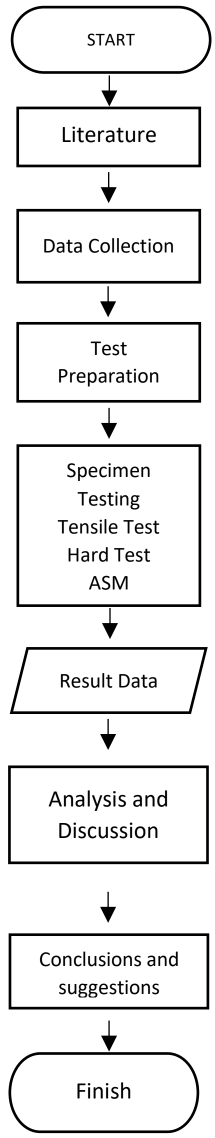

Figure 2.1 Flowchart

Literature Study At this stage, a review of relevant literature was conducted to obtain the theoretical basis and information related to the research topic. This literature study includes a review of journals, books, and other academic sources that discuss wire welding and microstructure testing. Tensile testing in order to determine how much the maximum tensile strength of the wire is after that conducting a test to determine the hardness of the welding results and then the Micro structure test, which is the process of testing the wire that has been welded in order to determine the mechanical properties of the wire structure.

Table 2.1 Specimen Codes

Current (%)	**Pressure (Mpa)** H (0,1) V (0,3)	**Pressure (Mpa)** H (0,15) V (3,5)	**Pressure (Mpa)** H (0,2) V (0,4)
59	A5913	A591535	A5924
60	A6013	A601535	A6024
61	A6113	A611535	A6124

The welding process has 3 variations, welding current (A) 59%, 60% and 61% each of the current variations has 3 pressure variations of 2 pressures that contribute during the welding process. Horizontal pressure supports the contact of the two end surfaces during the welding and melting process which has an impact on the melting thickness, (TL) melting diameter (DL) and Specimen Diameter (OD) of the welding results, vertical pressure serves to ensure good welding current contact and gripping when horizontal pressure is working. Horizontal pressure (H) has several variations, namely 0.1 Mpa, 0.15 Mpa and 0.2 Mpa, vertical pressure variations (V) are 0.3 Mpa, 0.35 Mpa and 0.4 Mpa. Specimen codes are used to summarise the specimen specifications of the research variations.

Table 2.2 Welding Parameters

Channel	**Heating Time (s)**	**Hold Time (s)**
1	0,6	2
2	1	2

Welding process parameters are applied to all welding variations. The welding parameters used are contained in Table 2.2, in the welding process there are 2 processes *channel 1* welding and *channel 2*, namely *tempering* heating.

Table 2.3 Welding Result Parameters

Thickness (mm)	**Melting Diameter (mm)**	**Specimen Diameter (mm)**	**Tensile Strength N/mm^2**
1 ± 0.5	Ø 2.5± 0.2	Ø 98,5	2500 (Min)

Welding outcome parameters are used to evaluate the success of the welding process in achieving the specifications achieved, as well as to ensure that the welded joints are of a quality that complies with the outcome standards

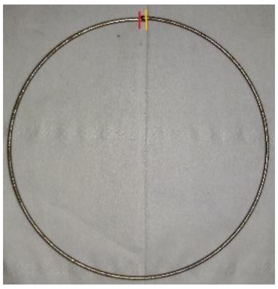

Figure 2.2 Welding Specimens

The welding specimen in this study is a spring steel wire JISG3521 Ø1.4 mm formed into a cylindrical shape Ø98.5 mm having an *overlap of* both ends of the surface of 2.2 mm, the red line is a cut on the left side and the yellow line is a cut on the right side. The specimen was welded with *resistance butt welding* technique. The shape of the specimen is cylindrical, the end of the piece that will enter the electrode *jig* groove made of copper with a groove depth in the form of a radius of 0.7 mm.

(a) (b) (c)

(d)

Figure 2.3 Measurement of Welding Results

Figure 2.3 illustrates the process of measuring welding results to determine the effect of variations in welding current and pressure on the characteristics of welded joints and evaluate the success of achieving specification standards. Figure 2.3(a) shows the melt thickness (TL) measurement, which determines the depth of melted material and the integrity of the joint. Figure 2.3(b) shows the melt diameter (DL) measurement, which is important for evaluating the fusion area and tensile strength of the joint. Figure 2.3(c) shows the tempering heating range measurement due to current variation, providing the extent of heat distribution that affects the mechanical properties and microstructure of the material. Figure 2.3(d) shows the measurement of specimen outer diameter Ø98.5 mm (OD), which is important to ensure the dimensional conformity of the specimen in order to measure and evaluate the achievement of specification standards.

3. Welding Result

Observations based on the results of *resistance butt welding* on JISG3521 spring steel wire carried out with different pressure variations.

Figure 3.1 Shape of Welding Results

In Figure 3.1 shows the welding specimens, point A marks the boundary of the *base metal* area, characterised by a brownish grey colour similar to the condition of the material before the welding process, point B marks the boundary of the *tempering* heating area in *channel 2*, where a dark grey colour is visible due to the application of a *tempering* temperature of 815.56 °C after welding, and point C identifies the melting area of the weld joint, characterised by a light grey colour resulting from the melting process of two metal surfaces brought together under pressure.

Table 3.1 Welding Thickness

Thickness of Melt (TL) 1±0.5mm				
Pressure (Mpa)		**Current Variation (%)**		
Horizontal	Vertical	59	60	61
0,1	0,3	1.84mm	1.45mm	1.63mm
0,15	0,35	1.93mm	1.50mm	1.82mm
0,2	0,4	1.96mm	1.65mm	2.0mm

Table 3.1 presents the dimensions of the melting thickness of the welding results with variations in current with some application of pressure variations in welding, the interaction of current and welding pressure has a direct influence on the dimensions of the melting thickness of the welding results. Based on Figure 3.2 presented in the graph, it can be seen that an increase in current generally increases the dimensions of the welding results.

Tensile Test Results

In the results of this Tensile testing at 59% current has the highest value of the 3 test samples with a value of F max 2051 Newton with very hard and brittle properties because the test results are cut off in the welding results which means the results are brittle and not recommended for use on wheel holder ornament parts.

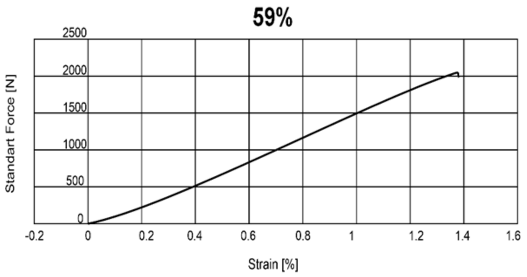

Figure 3.2 59% Tensile Test Curve

The tensile test results at 60% current have a high enough value of F max 1913 Newton, therefore this 60% current has material properties that are quite hard and ductile, it appears that the wire has good ductility. This is indicated by the neck (*necking*) on the wire specimen after testing. This neck is formed due to the plastic deformation experienced by the wire before fracture. The wire has an initial diameter of 1.4 mm and a final diameter of 1.30 mm. This shows that the wire experienced a diameter reduction of 0.1mm during the test. This diameter reduction is indicative of the plastic deformation that the wire underwent.

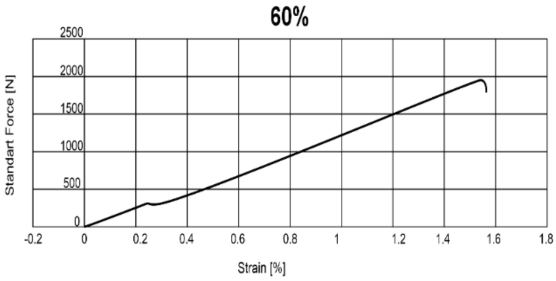

Figure 3.3 60% Tensile Test Curve

The results of the tensile test at a current of 61%, namely F max 547 Newton with these results the tensile strength value is very low among the 3 samples tested. Welding including optimal welding. shows that this test specimen has *failed* the welding process, resulting in a fracture at the melting point of the welding material, has a strength below the average and below the *tensile* strength *of* the material itself, caused by a combination of sufficient current with too little pressure, so that the material that should get welding does not experience sufficient melting.

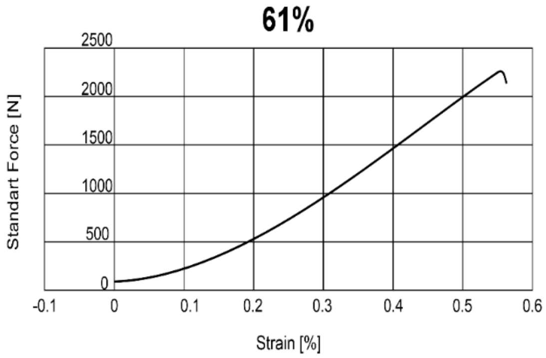

Figure 3.4 61% Tensile Test Curve

Hard Test Results

In the hard test results that Sample Current (1) 59% The results of these tests that the 59% current has a hardness of 405 HV this value is quite small among the 3 test samples, therefore the welding results with a current of 59% have quite hard properties. In Samples (2) and (3) experienced a not too significant increase with a hardness value of 408hv and 410 hv.

Table 3.2 Hardness Testing Results 59% (1)

Sample 1				
No	d1	d2	d AVG	HV
1	97,4	95,9	96,7	397
2	94,8	95,0	94,9	412
3	95,3	94,5	94,9	412
4	96,8	95,6	96,2	401
Avg HV				405
Load 2000 gf				

Tabel 3.3 Hardness Testing Result 59% (2)

Sample 2				
No	d1	d2	d AVG	HV
1	97,4	95,9	96,7	397
2	94,8	95,0	94,9	412
3	95,3	94,5	94,9	412
4	96,8	95,6	96,2	401
Avg HV				408
Load 2000gf				

Tabel 3.4 Hardness Testing Result 59% (3)

Sample 3				
No	d1	d2	d AVG	HV
1	29,72	34,76	32.24	397
2	35.09	33.01	30.92	412
3	29.42	34.76	32.09	412

4	29.42	35.09	32.26	401
Avg HV				410
Load 2000gf				

60% Current The results of this test at 60% current have a fairly high hardness value from among the previous test samples. This sample has a hardness value of 409 HV in sample (1), sample (2) 508HV and sample (3) 487HV.

Table 3.5 Hardness Testing Results 60% (1)

Sample 1				
No	d1	d2	d AVG	HV
1	95,4	94,4	94,9	412
2	95,9	95,3	95,6	406
3	94,8	95,0	94,9	412
4	96,1	94,9	95,5	407
Avg HV				409
Load 2000gf				

Table 3.6 Hardness Testing Results 60% (2)

Sample 2				
No	d1	d2	d AVG	HV
1	30.92	37.04	33.98	481.5
2	30.92	36.71	33.81	486.2
3	30.32	36.06	33.19	504.7
4	29.42	36.71	33.06	508.5
Avg HV				495.2
Load 2000gf				

Table 3.7 Hardness Testing Results 60% (3)

Sample 3				
No	d1	d2	d AVG	HV
1	32.92	37.04	33.98	400.5
2	39.92	36.71	33.81	487.2
3	30.32	36.06	33.19	509.7
4	29.42	36.71	33.06	500.5
Avg HV				497,0
Load 2000gf				

And at a current of 61% the hardness value at a current of 61% decreases significantly with a hardness of 406 in sample (1) sample (2) 407 and Sample (3) 406 and has a hardness level that is quite low compared to the previous one.

Table 3.8 Hardness Testing Results 61% (1)

Sample 1				
No	d1	d2	d AVG	HV
1	90,4	80,4	91,2	397
2	91,9	90,3	93,6	400
3	91,8	95,0	92,9	398
4	97,1	94,9	90,5	402
Avg HV				406
Load 2000gf				

Table 3.9 Hardness Testing Results 61% (2)

Sample 2				
No	d1	d2	d AVG	HV
1	90,4	80,4	91,2	397
2	91,9	90,3	93,6	400
3	91,8	95,0	92,9	398
4	97,1	94,9	90,5	402
Avg HV				407
Load 2000gf				

Table 3.10 Hardness Testing Results 61% (3)

Sample 3				
No	d1	d2	d AVG	HV
1	90,4	90,4	91,2	397
2	90,9	90,2	93,6	403
3	91,8	95,0	92,9	398
4	95,1	94,9	91,5	404
Avg HV				406
Load 2000gf				

Microstructure Testing Results

Ingeneral the heat current input affect the toughness value and the microstructure of the Weld Metal and HAZ regions.the microstructure in the Base Metal region is not influenced by variations in welding parameters so that the shape and size of the grains are relatively the same. At low electric current, the hardness value of the specimen will tend to be higher and inversely proportional if the electric current used in welding is getting bigger. Likewise, the tensile stress of each specimen and the heat current affect the microstructure results and determine the mechanical properties of the welding results.

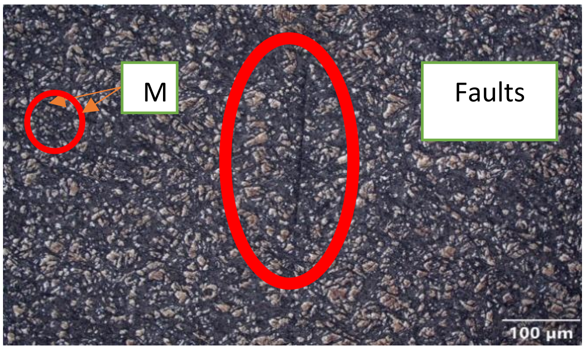

Figure 3.5 Microstructure Analysis of 59% (1)

The 59% welding result does not experience more heating during welding. because there is still a gap that is not melted properly when heating takes place in the welding process. As well as having hard and brittle properties that cause fractures between the two welding joints when in the Tensile test.

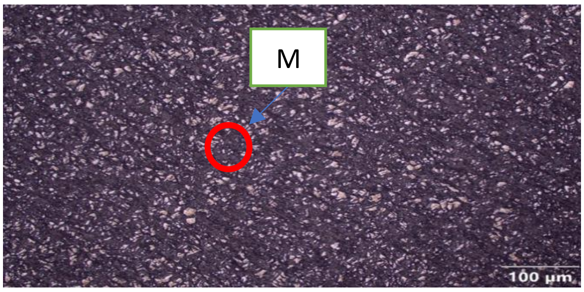

Figure 3.6 Microstructure Analysis of 59% (2)

The results of microstructure testing at a current of 59% welding results at this current have a fairly good level of melting because there are no gaps that are not welded to these results the properties listed in Figure 4.5 are martensite properties which have a fairly hard and ductile strength and welding results 59% is the optimal welding result.

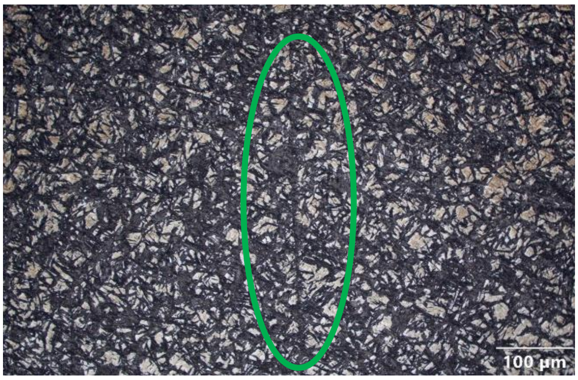

Figure 3.7 Microstructure Analysis 59 (3)

The green circle shows that the microstructure of the welding result contains martensite properties which has a hardness value of 409 HV. However, the 59% welding results are unevenly melted because there are still gaps that do not experience optimal melting from the welding and have hard, brittle properties and have carbon content> 0.5% which causes a fracture between the two welds when tested Pull.

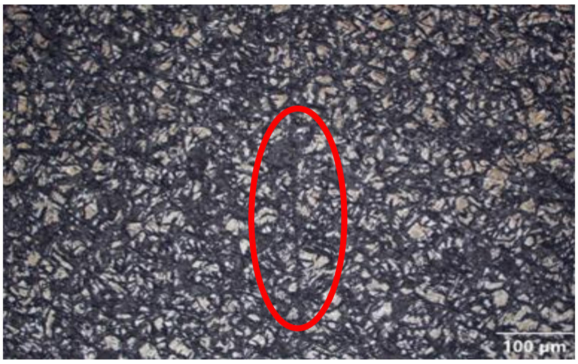

Figure 3.8 Microstructure Analysis of 60% (1)

At this magnification, the microstructure of the 60% welding results is martensite which has a fairly good hardness and strength value, but sample 1 has a fault line in the middle of the surface due to poor penetration during welding.

Figure 3.8 Microstructure Analysis of 60% (2)

In the results of the 2nd sample of 60% welding results, there is a fairly deep crack in the middle area due to lack of heating when welding takes place and due to the rate.

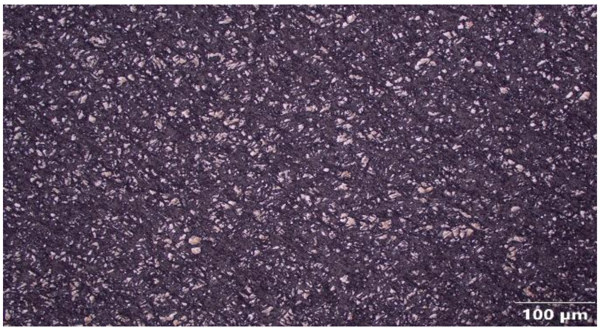

Figure 3.9 Microstructure Analysis 60 (3)

In this 3rd sample in the welding results that this result is quite better than the previous sample because in this result in the welding process the penetration is quite good, so in this result there are no fractures or cracks on the surface of the welding result.

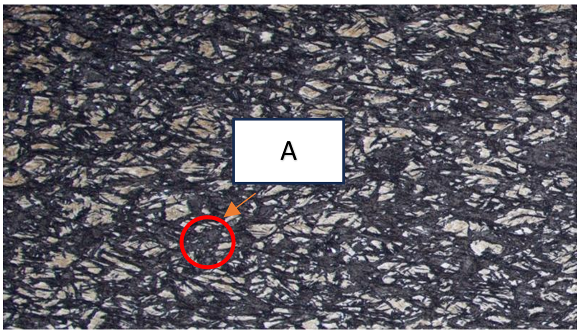

Figure 3.10 Microstructure Analysis of 61% (1)

In this sample, it is stated that the results are very good because there are no breaks or scratches in the welding results, so the penetration in this welding can be said to be better than the previous sample.


Figure 3.11 Microstructure Analysis of 61% (2)

In this sample, there are significant changes caused by excessive heat which causes heating penetration when welding quite well and has a long enough fracture in this sample so that the results of the 2nd sample do not meet the


Figure 3.12 Microstructure Analysis of 61% (3)

In this sample is a very good result than the previous sample because this samepl experienced good penetration with a high heating value so that this result is the best of this largest current.

4. Conclusion
   1. Current and Mechanical Properties will result in differences in heat distribution at the weld area, thus affecting the formation of microstructure. These different microstructures will have a direct impact on mechanical properties such as tensile strength, ductility, and hardness of the weld joint. As well as the selection of the right current is very important to obtain optimal weld joint quality. A current that is too small can cause incomplete penetration, while a current that is too large can cause defects such as pores or cracks. Because Electric current is one of the factors to determine the quality of welded joints.
   2. The acquisition of the value of the tensile strength test results in the 59% specimen of 2051 Newton has fracture characteristics (brittle and hard), the 60% specimen obtained a tensile strength result value of 1913 Newton characteristics (strong and tough). So that the 60% welding current variation has quite good specimen characteristics among the other 2 specimens. In the 61% specimen, the tensile strength result of 547 Newtons has a fracture characteristic (brittle) because this specimen breaks up in the welding results. So from this, the welding result that is quite good is the 60% variation because it has quite good values and characteristics between the 59% and 61% specimens.
   3. The result of the test is that the hard test in the area without a weld (HAZ) has a hardness of (559 HV) this value is very high compared to the hard test in the welding result area with an average value of (406 HV). because there is the influence of heat during connection in the welding process, therefore the welding results affect the hardness of the material caused by penetration during welding.

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Bibliography

[1] G. Singh, T. Sundarajan, K.A. Bhaskaran. 2013, "Mixing and entertainment characteristics of circular and noncircular confined jets." Journal of fluids Engineering, Transactions of The ASME, Vol. 125, 835-842.
[2] S. Mochizuki, H. Osaka. 1998, Drag reduction with submerged ribs and its mechanism in a turbulent boundary layer over d-type roughness. Proc Int Symp on Seawater Drag Reduction, Newreport, Rhode Island, 22-23 July, 121-126.
[3] J.P. Holman. 1986, Heat Transfer, Sixth Edition. McGraw-Hill, Inc. New York.
[4] Reynolds, C. Wiliam, Perkins, C. Henry. 1987, Engineering Thermodynamics, 2nd Edition. Erlangga, Jakarta.
[5] T.S. Yuli. 2013, Experimental Study of Cavitation Identification on 90° Elbow Based on Vibration Spectrum and Noise Level, Mechanical Engineering Final Project, ITS, Surabaya.
[6] P. Manceke, B. Winkler, B. Manhartsgurber, 2001, Magneto-rheological damper. US006623364B2,
[7] W.J Rachmeyer, F. Chain, 2005, Calibration and verification testing facilities using an orifice. www.engineering.udu.edu/cee/, accessed 21 July 2005.
[8] M.Hasbi. (2020) Microstructure.
[9] Products, X. M. (2021). Spring Wire Patented Cold-drawn Steel Wire for Mechanical Spring, Hard Drawn Steel Wire. *xinhuametal*, 3-10.