Experimental Study of Aluminium Joint Plate Between AA5052 with AA5083: Application on Hull Vessel Material

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Abstract*— generally, the planning of the material arrangement of the aluminum hull plate is always carried out at an early stage to obtain a material formation that has good economic value. One of the strategies used to obtain economic value in shipbuilding is the use of various grades of plate material. The grade of aluminum material that is often used on ships is the 5xxx series. Where this series has many grades that can be used as ship hull material options. The price difference for each grade of aluminum material for ships is a very influential variable on the economic value of shipbuilding. However, before being applied to shipbuilding, it is necessary to test the feasibility of aluminum plate connections with variations in plate grade. The aim is to provide clear information regarding the technical feasibility of selecting material grades. Therefore, in this study, a simulation will be carried out to test the strength of the plate connection with variations in the grade of aluminum material using the experimental method. The plate joint test is carried out using only the Tensile test in the laboratory with reference to the ASTM rules. The grades of aluminum plate materials used are 5052 and 5083. Connection formations are between 5052-5052, 5083-5083, and 5052-5083. From the test results, the largest average yield stress value is 202.34 N/mm^2 at the variation 5083-5083, the maximum average ultimate stress value is 261.70 N/mm^2 at the variation 5083-5083. For the variation of the 5052-5083 plate connection, it still has a yield stress value that is greater than the basic yield stress of the material, namely 142.97 N/mm^2. Where the percentage value of the achievement level of yield strength is 113.6% of the basic yield stress value of the material based on BKI rules. However, in achieving the ultimate stress value, it is still lower than the ultimate basic stress of the BKI rules standard material, which is 193.88 N/mm^2. Where the percentage value of the level of ultimate strength achievement is 70.5% of the ultimate basic stress value of the BKI rules standard material.

Keywords—aluminium, welding joint, plate, yield stress, ultimate tensile stress.

I. Introduction

A proper ship design should comply with technical and economic aspects, which means all calculations and planning should comply with classification society rules, and shipbuilding cost is inexpensive and of high quality. In recent years, the shipbuilding industry has been paying attention to the material issue because the material cost is varied among locations. Thus, naval architecture is making effort in ship design with material modification for application on vessel material.

One of the efforts is to vary the use of the material grades on the ship, this variation gives different prices which is based on material specification or grade. The modification of material grade usage aims at combining certain grade materials with other grade types particularly in application on ship hull. The composition of material grade will determine the shipbuilding cost, and the cost can be reduced by joining different material grades without being dominated by one grade type. Therefore, to establish a basic material selection in shipbuilding, this study was performed to examine the strength of material joints with different grades which will be described in this paper. This study will investigate the strength of the plate joint between Aluminium 5052 and 5083 grades. In this decade, aluminum alloys have received attention since aluminum has light mass, high strength, easy recycling and high corrosion resistance [1].

AA5083 material is chosen because it has excellent corrosion resistance and is suitable for structural application in transportation mode [2][3] AA5083 is good mechanical strength and become an alternative material in vehicle and shipbuilding industries [4]. AA5052 is selected due to being cheaper than AA5083 but Aluminium alloy AA 5052 was used as the matrix material of the composites since this alloy has superior corrosion resistance when compared with other alloys in the aluminium 5xxx series [5][6]. Meanwhile, the most important characteristic of AA 5052 aluminum alloy is Fusion welding of such alloys is difficult [7].

Many studies related to welding joint on aluminum materials have been performed. Rao et al (2013) performed a test on welding joint specimen of AA5083 plate using micro tensile dan finite element method (FEM) which is showing differences in material properties in the joint [8]. Moreira et al (2009) carried out a simulation of resistance test on the joint of AA6061 and AA6082 plates by welding, and the result shows a

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better resistance value in the joint with same grade [9]. Similar study has been performed by test on in the join of AA6351 and AA5083 grades, as a result, the combination of AA6351-AA6351 has a better resistance than the combination of AA6351-AA5083 [10]. Jesus et al (2017) has been carried out a test on the joint plate of AA5083 - AA6082 with T-butt dan T-lap configuration, it is obtained that the performance FSW T-butt is more than T-lap [11]. Lee et al (2003) tested a joint of AA5052 aluminum and A36 steel, the result shows a defect of the welding area in the aluminum material, but it has a maximum joint strength of 202 Mpa [12]. Shankar et al. (2002) attempted to carried out a welding joint simulation on a crack fast ship hull that uses AA5083 grade. The part that is experiencing cracks is given additional welding. Simulation result shows increasing of fatigue life on the plate joint after giving the treatment [13]. Khumbar et al. (2012) performed a joining between AA5052 and AA6061 aluminium, and carried out a tensile test on the specimen, a better mechanical property is obtained compared to mechanical properties of basic material of AA6061 plate joint [14]. Another case, the plate joint of AA6082-O has been tested for tensile test by varying the welding arch swing speed, and the result shows a significant difference of stress value with the speed welding arch swing of 70 mm/minutes [15]. This last case will be discussed in the next paper.

Based on the previous review, in the present study, a simulation of aluminium joint plate is carried out with combinations of 5052-5052, 5083-5083, and 5052-5083. This study aims to investigate the strength of the plate joint combinations using experimental method. The variation of this type of connection is tried to be investigated because it will be applied to ship construction at a shipyard in Kalimantan. One thing that is of concern to industry players is related to the strength of the welded joints on aluminum plates. We performed a tensile test with producing test specimens first, the tensile test refers to ASTM standards. II.

II. METHOD

A. Stress-Strain Concept

Stress is a statically derived quantity measured in the material of a structure. While strain is a kinematic quantity measured from the deformation that occurs in a structure. However, the magnitude of the deformation depends on the loads acting on the structure. The physical relationships that link these quantities are called constitutive laws. The value of this quantity depends on material and can only obtained with the help of experiments [16]. One form of experiment to determine the relationship between the two quantities is tensile testing. Here, a small specimen of the material is placed into a testing machine to determine the length increase test material after being given a load (F). The force applied to the specimen will produce a structural response called normal stress as in the following equation:

$$\sigma = F/A \tag{1}$$

In addition, there is also a strain (ε) obtained from the difference in length increment (Δl) compared to the initial length (l) as in the following equation:

$$\varepsilon = \Delta l/l \tag{2}$$

The relationship between stress and strain from the tensile test of the material is explained in **Figure 1.**

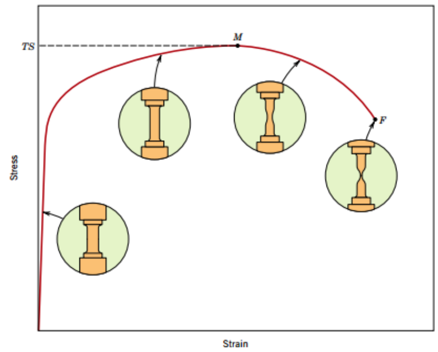


Figure. 1. Stress-Strain Curve: M identifies the value of tensile strength (TS); F identifies the fracture point in the material [17]

B. Material Data

In the present study, aluminum with 5052 and 5083 grades will be examined, and composition of those material is given in the **Table 1**. The plates are joined using metal inner gas (MIG) welding. This welding process used a continuous unwrapped/coated electrode wire. The metal transfer mode (spray, globular, short circuit, pulsed arc) varies by adjusting the amperage and used shielding gas depending on the welding position and type of connection [18] and its supply characteristic is continuous.

TABLE 1.
MATERIAL COMPOSITION [11] [13]

Chemical **Item**	**% Composition**	
	5052	5083
Al	Balance	Balance
Si	0.25	0.40
Fe	0.40	0.40
Cu	0.10	0.10
Mn	0.10	0.40–1.00
Mg	2.20-2.80	4.00-4.90
Cr	0.15-0.35	0.05-0.25
Zn	0.10	0.25
Ti	…	0.15

The weld area is protected from the atmosphere through the gas produced by the welding tool, as shown in **Figure 2**. The shielding gas used is argon gas, helium or a mixture of both.

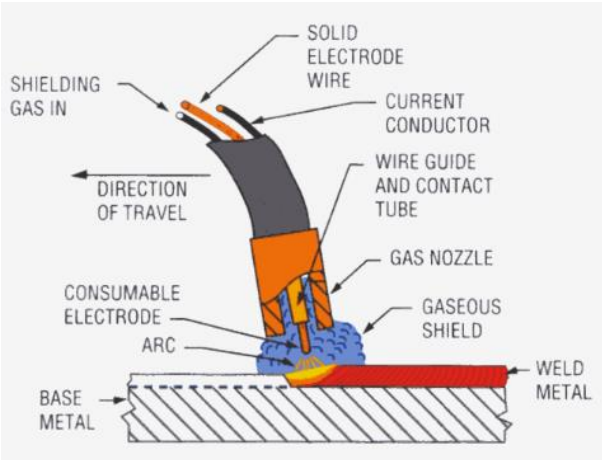
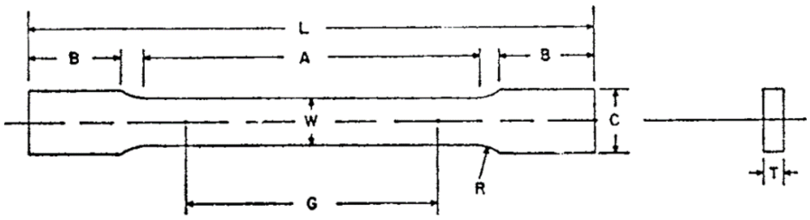


Figure. 2. Metal Inert Gas (MIG) Welding [12]

C. Experimental Set-Up

Shape and size of the tensile test specimen is standardized, in particular case, it is allowed to use non-standardized specimen. The standardized of shape and size specimen is also called proportional test specimens, while the non-standardized is called non-proportional test specimens. The specimen size in the present study refers to ASTM E3/E8M-13 tensile test specimen standard, the shape and size of the specimen can be seen in **Figure 3.**



Dimensions			
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1,500 in.] wide	Sheet-Type, 12.5 mm [0,500 in.] wide	6 mm [0.250 in.] wide
	mm [in.]	mm [in.]	mm [in.]
G- Gauge length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2,000 ± 0.005]	25.0 ± 0.1 [1,000 ± 0.003]
W-Width (Note 3 and Note 4)	40.0 ± 2.0 [1,500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T-Thickness (Note 5)		thickness of material	
R-Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L-Overall length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A-Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B-Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C-With og grip section, approximate (Note 4 and Note 9)	5- [2]	20 [0.750]	10 [0.375]

Figure. 3. Specimen Form based on ASTM [19]

The specimens are tested in this study consisted of the plate joint with grades of 5052-5052, 5083-5083 dan 5052-5083 and a thickness of 8 mm. The plates are welded using MIG welding with electrode properties like the following:

Alloy	: MTL 5356
Approvals	: LR, GL, DNV, ABS, BV, RINA
Diameter	: 1.2 mm
Net Weigth	: 7 kg
Specification	: EN ISO 18273 S-AL 5356
Yield Strength	: ≥ 120 MPa
Tensile Strength	: ≥ 250 Mpa
Elongation	: ≥ 18 %

With the typical analysis wire as shown in Table 2.

TABLE 2.
TYPICAL WIRE ANALYSIS

Item	Chemical Composition (wt-%)
Al	bal
Mn	0.05 – 0.2
Cr	0.05 – 0.2
Mg	4.5 – 5.5
Ti	0.06 – 0.2

Single V butt is used as shown in **Figure 4**. After welding the joint plate, the weld is tested using a non-destructive test method namely the penetrant test as shown in **Figure 5**.

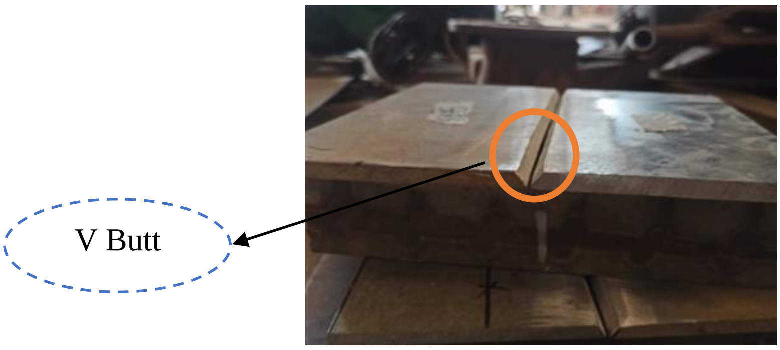


Figure. 4. Single V Butt

Figure. 5. Penetrant Application

After applying the penetrant, the next step is to spray the cleaner on the welding line and wait a few minutes to ensure the cleaner working optimally, red dots indicate that welding joint is experiencing a welding defect as shown in **Figure 6**. In this case, the welding joint will be replaced with the new one.

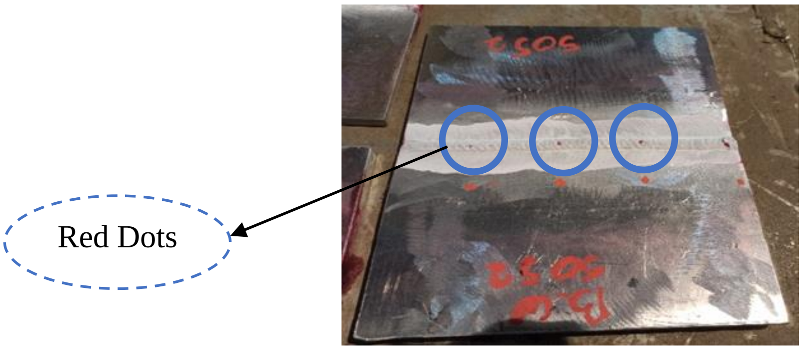


Figure. 6. Red Dots in welding line

Producing of test specimen is carried out after ensuring the plate joint without any defect, and three test specimens are produced for each joint variation. **Figure 7** shows the shape of test specimen referring to ASTM E3/E8M-13 tensile test specimen standard.

Figure. 7. Test Speciment

Re-measuring of the specimen will be carried out before performing a tensile test, and then starting tensile test on tensile machine. Tensile test is performed on the specimen until it breaks to obtain property values.

III. Results and Discussion

The tensile test has been carried out on three types of specimen variations, the test results are described as follows:

A. Specimen 5052-5052

In this test, three specimens are tested with referring to ASTM standards, and GIM welding id used. **Figure 8** shows the result of tensile test on this variation, and the material properties are given in **Table 3**.

Figure. 8. Test results of 5052-5052 Specimen

TABLE 3.
TENSILE TEST RESULT OF 5052-5052

Specimen Number	Yield Stress (N/mm^2)	Ultimate Tensile Strength (N/mm^2)
1	123.17	190.22
2	124.57	190.93
3	124.27	192.91
Average	124.00	191.35

Table 3 reveals that specimen 2 was experienced the highest yield stress, while the lowest was specimen 1 whit a percentage difference of 0.99 %. Similarly, specimen 3 had the highest ultimate tensile strength, and specimen 1 had the lowest, with a percentage difference such as the percentage difference with the yield stress discussed earlier. In addition, figure 9 gives the trend of stress and strain characteristics on three tensile test specimens.

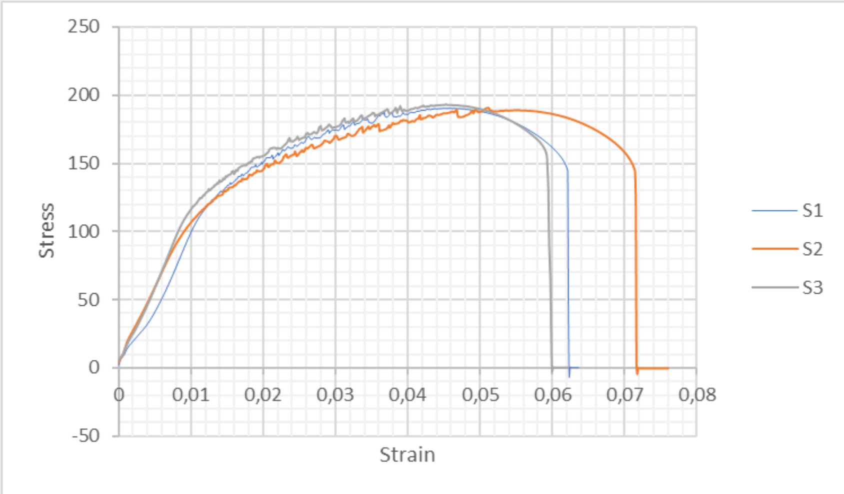


Figure. 9. Stress-Strain Curve of specimen 5052-5052

For this specimen, the test results show that the yield and tensile strength are still below the minimum BKI standard for aluminum material. However, for construction purposes in superstructures, variations in the grade of this material can still be considered. With the assumption, the load acting on the wheelhouse structure is less than the load on the hull below the waterline.

B. Specimen 5083-5083

Like previous variation, three specimens are tested in this tets with referring to ASTM using MIG welding. **Figure 10** reveals the tensile test results in this variation, and material properties are shown in **Table 4.**

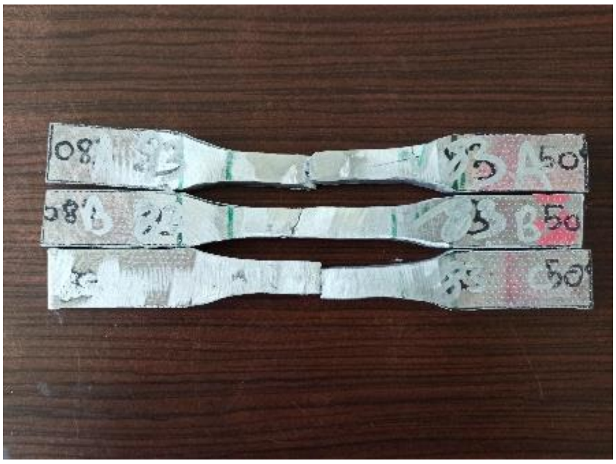


Figure. 10. Test Results of Specimen 5083-5083

TABLE 4.
TENSILE TEST RESULTS OF 5083-5083

Specimen Number	Yield Stress (N/mm^2)	Ultimate Tensile Strength (N/mm^2)
1	194.62	247.59
2	215.26	287.07
3	197.13	250.43
Average	202.34	261.70

Table 4 reveals that specimen 2 was subjected to the highest yield stress, and specimen 1 had the lowest value. Similarly, in the ultimate tensile strength, specimen 2 is the highest, and specimen 1 is the lowest with a percentage difference of 0.99%. Moreover, **Figure 11** shows the trend of stress and strain characteristics on three tensile test specimens.

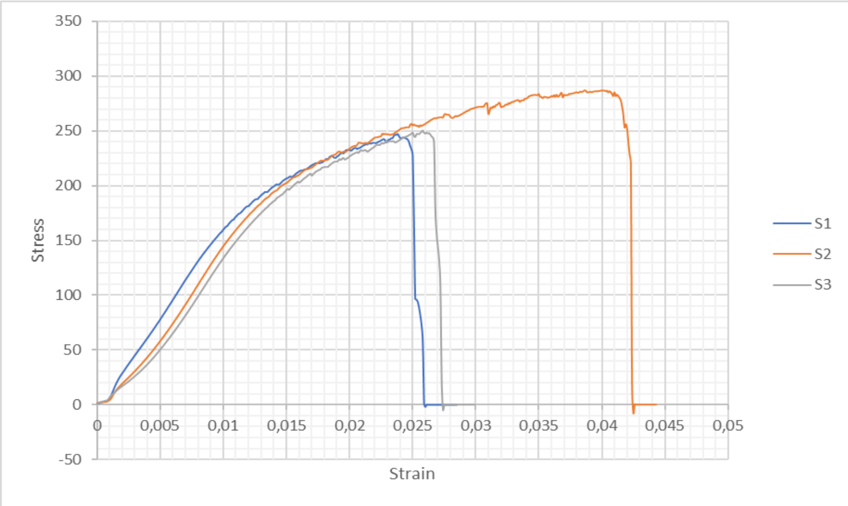


Figure. 11. Stress-Strain Curve of Specimen 5083-5083

The differences that occur in each specimen are very likely to occur due to differences in weld bursts on the welding line. Another thing that may happen to the specimen is the presence of weld defects that cannot be detected by non-destructive inspection of the penetrant type test. In the future, more specimens are needed to obtain property values with a better level of accuracy.

C. Specimen 5052-5083

Similarly, in this variation the number of specimens were three with referring to ASTM using MIG welding. **Figure 12** shows the tensile test result, and Table 5 gives the obtained material properties.

Figure. 12. Test Results of Specimen 5052-5083

TABLE 5.
TENSILE TEST RESULTS OF 5052-5083

Specimen Number	Yield Stress (N/mm^2)	Ultimate Tensile Strength (N/mm^2)
1	146,90	189,25
2	141,80	195,74
3	140,21	196,66
Average	142,97	193,88

Table 5 shows the value of yield stress and ultimate tensile strength of the specimen, like previous variations, specimen 3 had the highest value both yield stress and ultimate tensile strength, and specimen 1 was the lowest for both, with a percentage difference of 0,99%. **Figure 13** shows the trend of stress and strain characteristics on three tensile test specimens

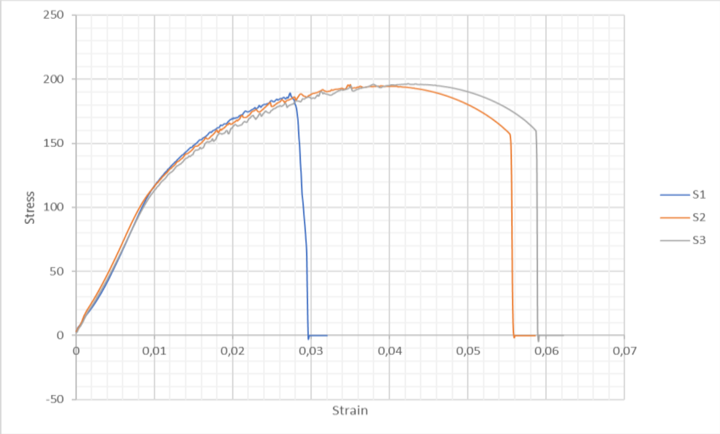


Figure. 13. Stress-Strain Curve of Specimen 5052-5083 Variation

from the test results, it shows the value of the yield strength that occurs in the specimen is still below specimen 5083-5083. But still better when compared to 5052-5052. By using the same type of electrode, the ultimate tensile strength value is also different. This can happen because the value of the alloying element content in plates 5052 and 5083 is different. In general, based on the results of this test, it shows the ability of the material to be used on ships, especially in superstructures. As for the hull structure, it still needs to be conditioned with the ship's trajectory that has varying wave loads.

D. Discussion

Three tests of the joint plates show the obtained difference in the material properties. The average value of material properties then is evaluated by Biro Klasifikasi Indonesia (BKI) Standards [20]. **Table 6** gives the comparison of the three materials.

TABLE 6.
EVALUATION OF MATERIAL PROPERTIES VALUE FOR ALL SPECIMENS

Variation	Average Yield Stress (N/mm^2)	Yield Stress (N/mm^2) BKI Standart	Average Ultimate Tensile Strength (N/mm^2)	Ultimate Tensile Strength (N/mm^2) BKI Standart
5052-5052	124,00	125	191,35	275
5083-5083	202,34	125	261,70	275
5052-5083	142,97	125	193,88	275

Table 6 reveals yield stress and ultimate tensile strength value of three test variations. the yield stress of 5052-5052 is lower than BKI standard. In contrast, 5083-5083 and 5052-5083 is above BKI standard. As for the average of ultimate tensile strength of three variations, all values did not comply with BKI standard, except 5083-5083 specimen, its value is above BKI standard. **Figure 14** shows the comparison of the stress distribution.

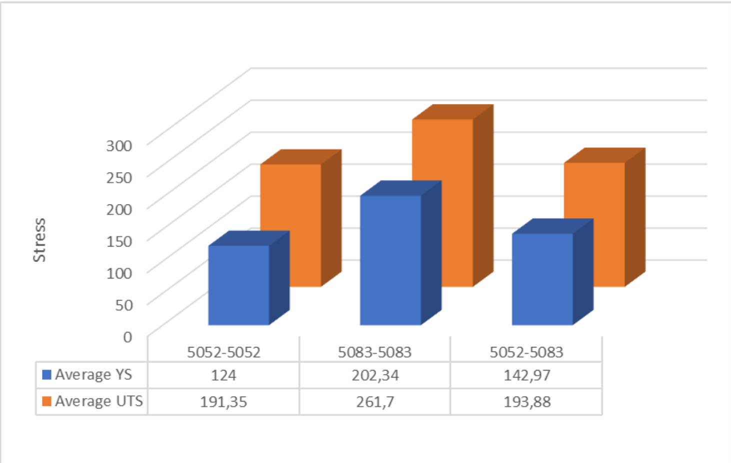


Figure. 14. Stress Distribution of Joint Variations

The test results of this study reveal that the aluminum joint plate with variation 5052-5083 grade is safe for ship structures that have an elastic stress (linear area) but not safe in plastic stress (nonlinear). Furthermore, it is necessary to conduct research related to the magnitude of the load that may occur on the hull of the ship. The aim is to see the response of the hull structure, especially the structural stress. The structural stress obtained is then compared with the results of the tensile test. For the time being, it is recommended that this type of connection can only be used in superstructures that have approximately a low construction load.

IV. CONCLUSION

An experimental test of 3 variations of the connection of aluminum plate material has been carried out successfully. The results show that the strength values in the three variations, namely 5052-5052, 5083-5083 and 5052-5083 are different. In the variation 1 test, the yield strength value is smaller than the BKI standard, only reaches 99% of the base stress of the material. Meanwhile, the ultimate stress shows the same trend, which is around 69% of the BKI standard. For the test of variation 2, it shows a better strength value than variation 1. The yield stress reaches 161% of the BKI standard, while the ultimate stress is lower than the BKI standard, which is 95%. The third variation shows a lower strength value than variation 2. Where the yield stress reaches 113.6% and the ultimate stress is 70.5% from the BKI standard. From these results, the recommended connection materials for the hull structure are variations 2 and 3. As for the superstructure, the three variations of the connection are possible to be used primarily.

Furthermore, it is highly recommended to test the weld defects on the specimen using an x-ray test to obtain better test results. In addition, variations of other aluminum grades need to be tested.

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