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Analysis of Selection of Alternative Materials Outer Support Solar Water Heater

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ABSTRACT

In the process of manufacturing a product, the manufacturing industry always prioritizes safety, quality, and profitability. One product that adheres to these criteria is the outer support for solar water heaters. Currently, the material used for the outer support of solar water heaters is SS 304. In this study, an analysis of alternative materials for the outer support of solar water heaters was conducted with the aim of finding materials that can fulfill the outer support function at a relatively lower cost, without compromising its functionality, and are readily available or abundant in the market. The methodology employed in this study utilizes the Analytical Hierarchy Process (AHP) and CES Edupack software for the material selection process. Several mechanical property tests were conducted, including tensile tests, hardness tests, and corrosion resistance tests, to determine the mechanical properties of the materials. Based on the outcomes of the three material tests, we have identified alternative materials that adhere to the material criteria established by the manufacturing industry for the outer support of solar water heaters, specifically AISI 304 and AISI 201.

KEYWORDS

Outer support
Solar water heater
Analytical hierarchy process
CES edupack

INTRODUCTION

A solar water heater is a device or system designed to generate hot water using solar energy. The principle of operation involves capturing sunlight through solar panels or solar collectors, which then convert that solar energy into heat [1]. This heat is used to warm water stored in a specially designed tank or cylinder. The hot water can be utilized for various purposes, such as bathing, dishwashing, space heating, or even industrial processes [2]. There are several types of solar water heater products, namely the SR130L1, SR150L1, and SR300L2 types [3]

The outer support of a solar water heater is a component of the solar water heating system that serves as the structural support or physical framework for the solar panels and the hot water storage tank [4]. This component is responsible for securely and stably holding and supporting the solar panels or solar collectors and the storage tank in an appropriate location, typically on the roof of a building or in an area with optimal sunlight exposure [5].

The outer support must be well-designed to withstand the mechanical loads of the solar collectors, the storage tank, as well as environmental factors such as wind and external weather

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conditions [6]. The selection of suitable materials and robust construction is crucial to ensure durability and good performance throughout the lifespan of the solar water heating system [7].

Furthermore, the outer support also plays a role in enhancing the operational efficiency of the solar water heating system by adjusting the position and angle of the solar collectors to capture as much sunlight as possible on sunny days. This helps maximize the production of hot water using the available solar energy source [8].

The material currently used in the outer support solar water heater type SR150L1 is SS 304. In producing a product, the company always prioritizes safety, quality, and profit. To meet these criteria, it is necessary to conduct research before producing it [9]. One of the studies carried out is to determine the materials used and the manufacturing process. Currently, there is a problem, namely the difficulty of finding SS304 material for outer support so the price is high and affects the profit of the company. Materials for the outer support that are difficult to procure may impede the production process, potentially causing delays. Hence, a solution is required to stabilize the production process of outer supports for solar water heaters [10].

The solution that can be done to overcome this problem is to replace the material. The selection of alternative materials is carried out without reducing the function of the outer support. This research is focused on selecting alternative materials for outer support solar water heaters using the Analytical Hierarchy Process (AHP) method [11].

The AHP method is a method used in problem-solving, using AHP a complex problem can be decomposed into groups that are then arranged so that it becomes a form of the hierarchy so that the problem will be more structured and systematic [11].

Previous research related to material selection using the AHP method has been conducted by Syamsun et al (2018). Their study focused on a decision support system for selecting stainless steel models for kitchen sets using the AHP method. The results of their research indicated that SUS 304 material is the most suitable material for use in kitchen sets with an eigenvalue of 0.356, followed by SUS 201 material with an eigenvalue of 0.306, and then SUS 316 material with an eigenvalue of 0.253 [12].

In this study, the AHP method was used to determine the criteria for materials that are very important in the solar water heater outer support material and choose alternative material candidates for the outer support solar water heater using AHP and strengthened by the Ashby Method, namely using CES Edupack software.

MATERIALS AND METHOD

The stages of this research are divided into 2 stages, namely material selection using the Analytical Hierarchy Process Method and Ashby Method, as well as material testing stages for 3 selected materials, namely tensile test, hardness test, and corrosion test [13]

The following are the stages of material selection using the AHP method:

1. Defining goals by means of defining the problem.
2. After the problem is defined, decomposition is carried out, that is, the whole problem is broken down into its elements in a hierarchy of criteria and alternatives [14]
3. Make a comparative assessment in pairs, designed to give an assessment of the relative importance of the two criteria at a certain level. The assessment affects the priority of the existing elements. By the relative comparison of the two elements can be known the degree

of importance between the criteria. Pairwise Comparison Assessment:
Value 1 = equally important
Value 3 = slightly more important
Value 5 = more important
Value 7 = very more important
Value 9 = absolutely more important
2,4,6,8 = middle value

4. Priority synthesis by calculating the value of the eigen vector for each matrix.
5. Calculate the consistency ratio (CR) by using the formula:
   CR = consistency rasio
   CI = consistency indeks
   IR = indeks random consistency
   to find out the consistency index (CI) can be searched by using the formula:
   n = Number of elements

$$CR = \frac{CI}{IR} \quad (1)$$

$$CI = \frac{(\lambda maks - n)}{n - 1} \quad (2)$$

6. The value of the random consistency index is obtained from the table of the Index List of random consistency.

Table 1. Index Value of Random Consistency

Matrix	IR Value
1.2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Material Selection with Ashby Method (CES Edupack)

In this stage, material selection is carried out by entering criteria for obtaining data in the form of a material suggestion chart. This method is used to assist in the determination of material alternatives to the AHP method, especially in terms of material rating on each criterion [15].

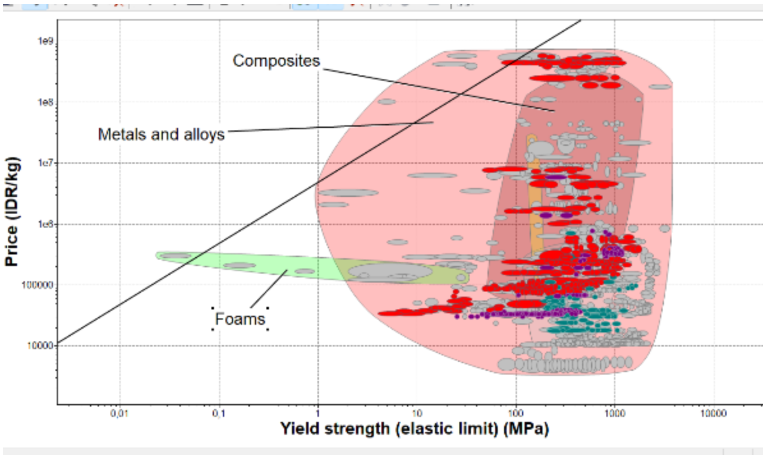

Figure 1. Chart of Materials Based on CES Edupack

Testing of Mechanical Properties

Material testing aims to determine the mechanical properties of the three material candidates who have been selected using the AHP and Ashby methods. The mechanical properties tests carried out are tensile tests, hardness tests, corrosion resistance tests.

1. Tensile tests
   Tensile testing is performed using the ASTM E8M standard. Tensile testing aims to determine the value of yield strength and the value of elongation. The relationship between the load or force exerted is directly proportional to the change in the length of the material. It corresponds to Hooke's law where the relationship between stress and strain is constant [5].
2. Hardness tests
   The hardness testing carried out in this study was using the Vickers method, with a diamond indentor penetration angle of 136°. Vickers hardness can be calculated using the following equation [6].

$$VHN = 1{,}854\,\frac{P}{d^2} \tag{3}$$

VHN = Vickers Hardness Number
P = Applied Load (kgf)
d = Length of indented trace diagonal

3. Corrosion resistance tests

   Corrosion testing carried out in this study uses the weight loss method, testing aims to determine the inhibition efficiency of the selected alternative material candidate. Corrosion testing is carried out by immersing in the selected alternative materials using a 3.5% NaCl solution [7].

$$Corrosion\ rate\ (mpy) = \frac{(\omega 0 - \omega 1)x\ 8{,}76\ x10^4}{a.t.d} \quad (4)$$

mpy = millimeter per years
$\omega 0$ = Initial weight of the sample (gr)
$\omega 1$= Sample weight after corrosion(gr)
a = Cross Sectional area (cm^2)
t = Time (h)
d = Density (gr/cm^3)

RESULT AND DISCUSSION

Determination of material criteria was carried out by distributing questionnaires to the head of the engineering and development division of Manufacturing Industry [16]. Based on the results of the questionnaire, the criteria for alternative materials for outer support materials are:
1. Able to withstand loads
2. Corrosion resistance.
3. Processability
4. Wear resistance
5. The price of the material is relatively cheap

Materials Recommendation Based on CES Edupack

Figure 2. shows the results of material recommendations for outer support. In determining the five material candidates, the consideration of material availability in the market is also an important factor. So that from these results, five material alternative candidates were obtained, namely AISI 304, AISI 316, AISI 201, AISI 1020, and Aluminum 5052.

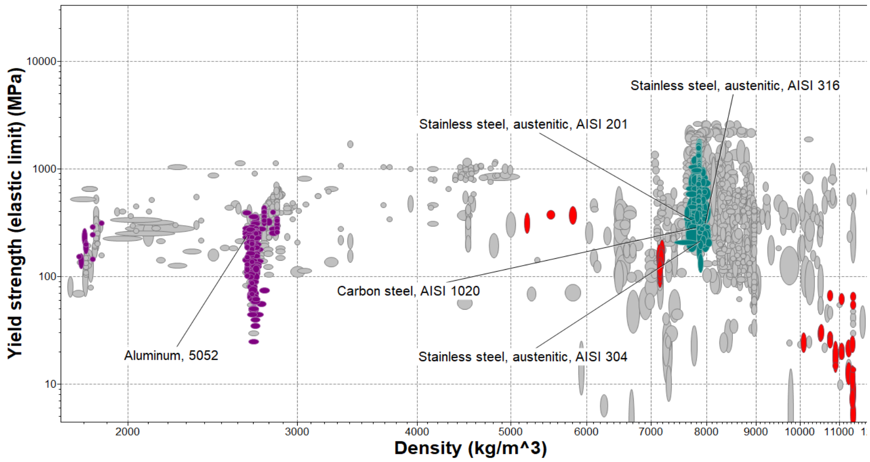

Figure 2 Materials Recommendation Based on CES Edupack

Materials Recommendation Based on Analytical Hierarchy Process

Based on the results of the identification of material criteria and the results of material recommendations using CES Edupack software, a decentralized analysis was carried out and arranged in a hierarchical structure as shown in Figure 3.

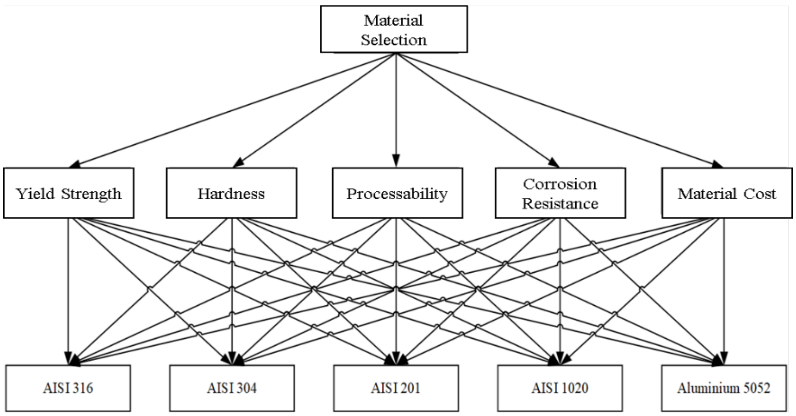

Figure 3. Materials Recommendation Based on AHP [11]

Comparison between criteria in the form of a pairwise comparison matrix is carried out with the aim of finding consistency from the data, namely a CR of less than 0.1 [11]. Table 2 shows the criteria comparison matrix which shows the priority criteria in the selection of alternative material outer support solar water heater.

Table 2 Comparison Matrix of Criteria

Criteria	Tensile Strength	Corrosion Resistance	Processability	Hardness	Materials Cost
Tensile Strength	1	0.5	5	5	0.33
Corrosion Resistance	2	1	7	5	0.5
Processability	0.2	0.142	1	0.33	0.142

Criteria	Tensile Strength	Corrosion Resistance	Processability	Hardness	Materials Cost
Hardness	0.2	0.2	3	1	0.2
Material Cost	3	2	7	5	1

After the comparison of each alternative, the next step is to do a material rating. The ranking is obtained by calculating the total global priorities [17]. Based on Table 3, the selection of alternative materials for outer support solar water heaters using the Analytic Hierarchy Process (AHP) approach, it is found that AISI 201 stainless steel material is the best material that can be chosen for the manufacture of outer support by having a combination of strength criteria, corrosion resistance, ease the of process, hardness, and material costs that are better than other materials [12].

Table 3 Ranking of Material

Material	Total Global Priorities	Ranking
AISI 201	0.2705	1
AISI 316	0.1716	4
AISI 304	0.2055	3
Aluminum 502	0.0917	5
AISI 1020	0.2605	2

Material Testing Results

Tensile Test

Tensile testing was performed on the top three alternative materials from the AHP method selection process [9]. The top three alternative materials are AISI 201, AISI 304, and AISI 1020. Table 4 shows the results obtained from tensile testing are ultimate tensile strength, yield strength, and elongation.

Table 4 The Result of tensile test

Specimen	Ultimate Load (N)	Yield Point (N)	Ultimate Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)	Elongation (%)
AISI 1020	18710	12810	415,04	284,16	36,60
AISI 201	37070	22950	631	390,95	15,60
AISI 304	30190	11630	642	247,32	60,40

From Table 4, the largest yield strength value is material AISI 201 of 390.95 MPa, and the smallest value is AISI 304 with a yield strength value of 247.32. The maximum tensile strength value in AISI 304 has the largest tensile strength value of 642 N/mm^2.

Hardness Test

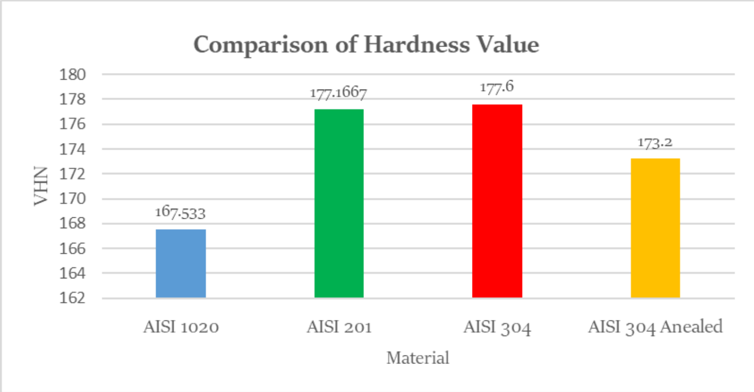

Figure 4. Graph of Hardness Value

Hardness testing was performed on the top 3 alternative materials using the Vickers method. The load carried out in this test was 0.2kgf with a holding time of 10 seconds. [18] The results of the tests carried out are in the form of digital data. Based on the test data obtained, the AISI 1020 material has a hardness value of 167.3 VHN. Then for AISI 201 material which is 177.17 VHN and for Material AISI 304 before annealing has a hardness value of 177.6 and after annealing, the hardness value decreases to 173.2 VHN.

Corrosion Resistance Test

The corrosion resistance testing was conducted to determine the corrosion rate of each material. The method used was the weight loss method with immersion for 7 days using a 3.5% NaCl solution. Figure 5 sows the result of corrosion resistance [19][8].

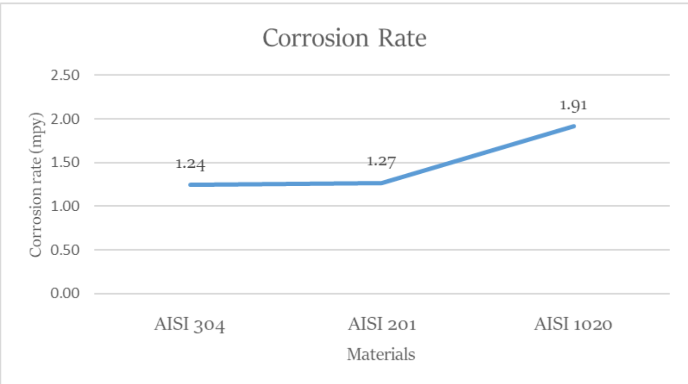

Figure 5. Graph of Corrosion Rate

Based on the results of the corrosion resistance test, it can be seen that AISI 304 Material has the best corrosion resistance, then AISI 201, and AISI 1020. This is because AISI 304 and AISI 201 have a chromium content of 12%, so the material is resistant to corrosion. While AISI 1020, where AISI 1020 is low-carbon steel, which has a carbon content of 0.2% and is easily subject to corrosion.[20]

The simulation result using Solidworks

Simulation was carried out for the top-ranked alternative material recommendation based on the AHP method calculation [18][8] Figure 6 shows the results from this simulation include maximum stress and safety factor values.

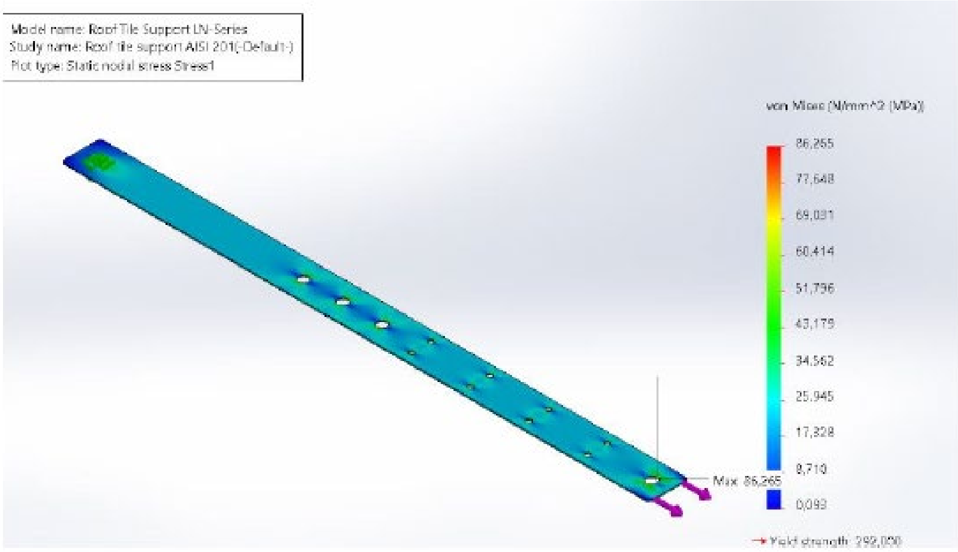

Figure 6. The maximum stress value

The simulation results for the outer support showed a maximum stress of 86.265 N/mm2.

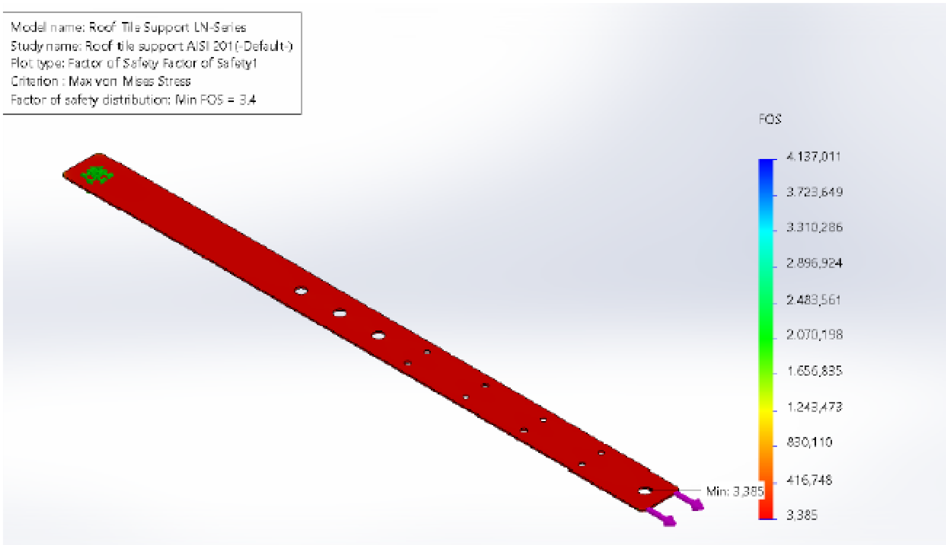

Figure 7. The safety factor value of AISI 201

The simulation results for the outer support yielded a safety factor of 3.4, indicating it is considered safe as the safety factor exceeds 1.8. This represents a 41.66% increase in safety factor compared to the previous material, which was AISI 304. The safety factor value for the outer support with AISI 304 material can be seen in Figure 8.

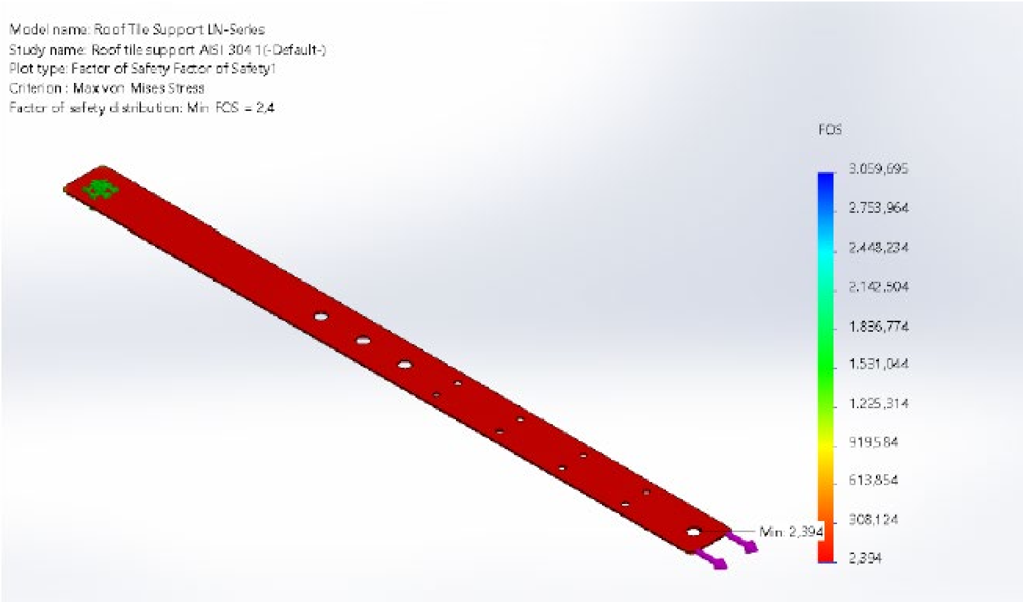

Figure 8. The safety factor value of AISI 304

CONCLUSION

Based on the results of 3 material tests, an alternative material was obtained for the outer support solar water heater that was in accordance with the material criteria from manufacturing Industry, namely AISI 304 and AISI 201. The hardness test results revealed the best hardness value for AISI 201 at 177.17 VHN, while the tensile test results showed a yield strength value of 390.35 MPa for AISI 201 material.

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