Cost Analysis Of FCAW And SMAW Welding On ASTM A36 Steel Plate Using Backing Ceramic Method At Company X

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***Abstract*— Welding is a highly essential process in various industrial sectors, particularly in shipbuilding, general engineering, and other fields related to structural joining. Welding is a technique used to join two or more metal parts by melting a portion of the base material at the joint area using heat or pressure, with or without filler material. Once cooled, the molten metal solidifies and forms a strong bond. In product fabrication planning, several aspects must be considered, including design, cost, materials, and the mechanical strength of the structure. This study aims to compare and optimize the welding costs between two commonly used methods, namely Flux-Cored Arc Welding (FCAW) and Shielded Metal Arc Welding (SMAW), applied to ASTM A36 steel plates using the backing ceramic technique. The comparison focuses on identifying which method is more efficient in terms of cost, work time, and weld quality. Data were obtained through field observation, operational cost calculations, and weld quality evaluations based on industry standards. The results of the analysis indicate that the FCAW method combined with Backing Ceramic offers greater efficiency than the SMAW method, especially in terms of faster welding speed and reduced labor costs. Additionally, the use of Backing Ceramic helps minimize welding defects and reduces the need for rework. Therefore, the implementation of FCAW with backing ceramic is considered a viable alternative for welding projects in Company X to improve production efficiency and effectiveness.**

***Index Terms*—Welding Cost; FCAW; SMAW; ASTM A36 Steel; Backing Ceramic**

I. INTRODUCTION

Welding technology has made significant progress and is now capable of supporting the manufacturing process of various constructions more optimally, whether for simple or complex structures that require high quality standards. In the industrial world, welding skills are an important aspect, especially in the shipping sector, general engineering, and other fields related to structural joining. Welding itself is the process of joining two or more metal parts by melting a portion of the joint area using heat or pressure, either with or without the addition of filler metal. After the molten metal cools, it hardens and forms a strong joint. In the planning stage of fabricating a product, various aspects such as design, cost, material type, and material strength must be thoroughly considered. The level of production profit is highly dependent on cost efficiency, particularly production costs. If production costs are too high, the company's ability to compete in the market will decrease. Therefore, detailed cost estimates are required at every stage of the process, from cutting to turning [1].

Welding plays a crucial role in manufacturing activities, as it is the primary method for joining metals. Generally, the value of a product is calculated based on its weight. In determining accurate welding cost estimates, several factors must be considered, such as the type of metal used, the welding joint type, material thickness, electrode melting rate, and welding position [2]. In the shipbuilding industry, welding processes must comply with standards set by the classification body responsible for determining the structural integrity of ships. This is crucial because ships operate in aquatic environments subject to forces such as wave pressure and hydrostatic forces, and must be able to support heavy loads. Therefore, structural strength and ship safety are top priorities. To meet the demands of ship owners and classification standards, the skills of a welder are highly sought after. Thus, ship welding techniques must be carried out in accordance with regulations to ensure the quality of the welded joints is acceptable. Given the large volume of welding work on ships, a welder must possess advanced technical skills as well as a thorough practical and theoretical understanding to produce high-quality welds.

Welding techniques in ship construction involve the joining of ship steel components, which must be carried out in accordance with applicable shipbuilding standards. In practice, welding on the ship's hull involves various stages depending on technical requirements. Although it looks simple, this process is actually highly complex and requires multidisciplinary understanding to be completed properly. Therefore, when designing a ship structure with welded joints, attention is not only focused on the welding technique, but also on the selection of suitable welding materials, the type of welding used, and the welding inspection procedure [3].

II. LITERATURE REVIEW.

A. *Flux Cored Arc Welding*

Flux Cored Arc Welding is one of the most commonly used welding methods in shipbuilding, particularly for joining steel plates of significant length. In FCAW welding, an electric arc is formed and maintained between a continuously fed filler metal electrode and the weld pool that is created. Both the arc and the weld pool are protected from contaminants by a slag layer produced by the reaction of the flux material [4].

B. *Shielded Metal Arc Welding*

Shielded Metal Arc Welding is a welding method that uses electric current to generate an electric arc through a flux-coated electrode. During the welding process, a protective gas is naturally formed when the flux coating on the electrode melts, so no additional pressure or supply of inert gas is required to protect the joint from the effects of oxygen or air, which can cause corrosion or bubbles in the welded product. The welding process occurs due to the electrical resistance between the electrode and the material being welded, generating extremely high temperatures, around 3000 degrees Celsius, which is sufficient to melt the electrode and the material to be joined.

C. *ASTM A36 Steel*

ASTM A36 is a standard specification for structural carbon steel, which includes various forms such as plates, bars, and other steel profiles with structural quality. This steel is generally used in the construction of bridges, buildings, and other structures that are joined using nails, bolts, or welding techniques. This material consists of an iron-based alloy (Fe) and is one of the most commonly used types of steel in the construction industry due to its superior mechanical properties and relatively economical cost. ASTM A36 steel has yield strength of 36,000 psi and a tensile strength ranging from 58,000 to 80,000 psi [5].

D. *Backing Ceramic Method*

Backing Ceramic is a ceramic welding backing material used to facilitate the welding process. Its function is as a layer or cushion on the back of the weld joint. Backing Ceramic plays a crucial role in ensuring better welding penetration and producing higher-quality weld joints. This material is widely used in various welding applications, such as stainless steel, carbon steel, and other materials requiring full penetration welding. Backing Ceramic welding features a wider foil design, responsive to heat and pressure. Its use can reduce defects, minimize rework, and reduce the need for costly engraving and grinding processes. Typically, Backing Ceramic welding is available in standard sizes ranging from 1/4 inch (6.3 millimeters) to 2 inches (50.8 millimeters).

E. *Welding Cost Component*

Welding cost components are elements involved in the calculation of welding process costs. In this case, the elements involved have a role and influence on the welding process. There is several cost components involved in the welding process, namely material costs, labor costs, energy costs, equipment and depreciation costs, and ceramic backing costs.

III. RESEARCH METHODOLOGY

A. *Break-Even Analysis*

Break-Even Analysis is a method used to determine the number of product units or sales volume that must be achieved so that total revenue is balanced with total costs incurred, thereby placing the company at a point where there is neither profit nor loss. In the field of welding, this method is useful for calculating how many welding projects need to be completed in order to cover all operational costs that have been incurred [6].

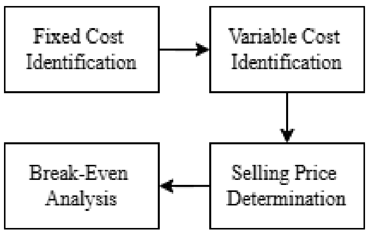

Fig 1. Break-Even Procedure

Break-even point calculation using the following formula:

$$\text{Break} - \text{Even (unit)} = \frac{\text{Fixed Cost}}{\text{Selling Cost} - \text{Variable Cost}}$$

Fig 2. Break-Even Formula

B. *Activity-Based Costing*

Activity-Based Costing (ABC) is a cost calculation method that allocates costs to products or services based on the activities performed during the production process. This approach provides more detailed and accurate cost information for each activity, thereby helping companies make more effective and targeted decisions [7].

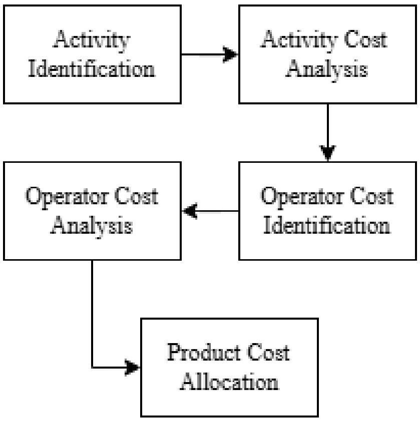

Fig 3. Activity-Based Costing Procedure

C. *Test Material Spesification*

This research process involves testing stages, which use the following test object specifications:

- The material used is ASTM A36 steel plate.
- The thickness of the steel plate is 10 mm.
- The welding position used is 1G.
- The welding current used is 100 A, 120 A, and 140 A.
- The welding methods used are FCAW and SMAW.
- A ceramic backing medium is used.
- The type of fillet used is V-type.

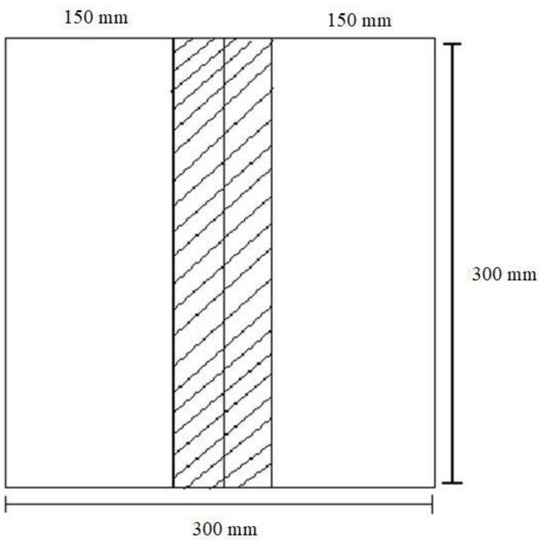

Fig 4. Test Specimen Specifications (Top View)

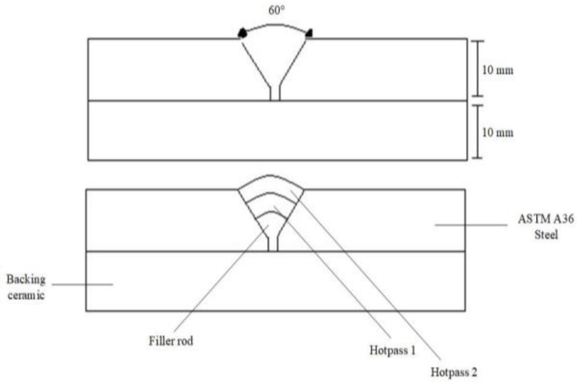

Fig 5. Planning The Shape Of Test Specimens

IV. RESULT AND DISCUSSION

A. *Welding Spesification*

The welding testing process carried out has specifications that serve as limitations in this study. Based on the specifications used, several elements listed are the result of adjustments to the standards used by PT. Janata Marina Indah in carrying out the welding process. The following are the welding specifications used in this study.

TABLE I. WELDING SPESIFICATION

Welding Method	FCAW And SMAW
Plate Material	ASTM A36
Welding Length	30 cm
Welding Current	100 A, 120 A, 140 A
Voltage	20 Volt
Machine Efficiency	80%
Electricity Cost	Rp 1.500/kWh
Welder Wage	Rp 30.000/jam
FCAW Electrode	Rp 75.000/kg (90% efficiency)
SMAW Electrode	Rp 60.000/kg (65% efficiency)
Backing Ceramic	Rp 20.000/meter

Source: Interview result of PT. Janata Marina Indah

B. *Welding Test Result*

1) *Flux Cored Arc Welding (FCAW)*

Based on the results of the welding experiments that have been carried out by applying FCAW (Flux Cored Arc Welding) welding in the 1G position and using the Single V Butt Joint weld, different Heat input results were obtained in each welding process, as listed below:

TABLE II. FCAW EXPERIMENT RESULT TABLE

Ampere (A)	Joint	Voltage (V)	Welding Speed (cm/min)	Time (min)	Heat Input (Joule)
100 A	60	20V	12 cm/min	2.5 minutes	10,000 Joules
120 A	60	20V	14 cm/min	2.14 minutes	8,571 Joules
140 A	60	20V	16 cm/min	1.87 minutes	7,500 Joules

Based on the table above, the experiment was carried out three times with different amounts of amperes of current, namely 100 A, 120 A, 140 A. The difference in current causes the heat produced (heat input) per layer is different, namely 10,000 Joules, 8,571 Joules, 7,500 Joules.

2) Shielded Metal Arc Welding (SMAW)

Based on the results of the welding experiments that have been carried out by applying SMAW (Shielded Metal Arc Welding) welding in the 1G position and using the Single V Butt Joint weld, different heat input results were obtained in each welding process, as listed below:

TABLE III. SMAW EXPERIMENT RESULT TABLE

Ampere (A)	Joint	Voltage (V)	Welding Speed (cm/min)	Time (min)	Heat Input (Joule)
100 A	60	20 V	14 cm/min	2.14 minutes	8,571 Joules
120 A	60	20 V	16 cm/min	1.87 minutes	7,500 Joules
140 A	60	20 V	18 cm/min	1.66 minutes	6,666 Joules

Based on the table above, the experiment was carried out three times with different amounts of amperes of current, namely 100 A, 120 A, 140 A. The difference in current causes the heat produced (heat input) per layer is different, namely 8,571 Joules, 7,500 Joules, 6,666 Joules

3) FCAW And SMAW Heat Input Development

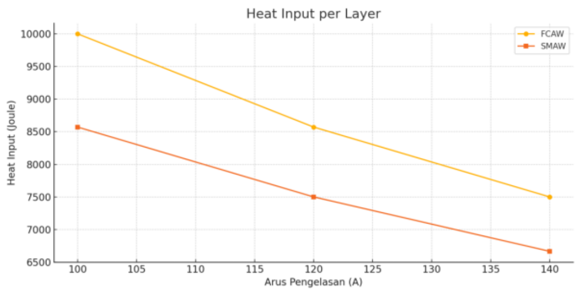

Fig 6. Heat Input Graph per Layer

This graph shows the relationship between welding current (A) and heat input per layer in two welding methods, namely FCAW and SMAW. It can be seen that as the current increases from 100 A to 140 A, the heat input given actually decreases in both methods. This may seem unusual, but it could be due to adjustments in welding speed or other parameters as the current increases.

Based on the graph above, the FCAW method consistently produces higher heat input than SMAW at every current point. For example, at a current of 100 A, FCAW produces about 10,000 Joules, while SMAW is only about 8,600 Joules. When the current reaches 140 A, the FCAW heat input value drops to around 7,500 Joules, and SMAW to about 6,600 Joules.

In general, this shows that even though the current is increased, the heat input is actually reduced. So this indicates that other factors such as electrode movement speed or heat transfer efficiency also have a major influence on the welding process. Then the importance of method selection is also clearly illustrated that FCAW provides higher heat input which has an impact on weld penetration and the microstructure of the welding results.

C. Welding Cost Calculation

FCAW and SMAW welding cost details on ASTM A36 plate with Ceramic Backing, using currents of 100 A, 120 A, and 140 A. This Ceramic Backing method is commonly used for root welding so that the weld results are clean on the back side and can reduce repetition of work. To calculate the cost details of the FCAW (Flux Cored Arc Welding) and SMAW (Shielded Metal Arc Welding) welding process on ASTM A36 plate, we need to take into account several components.

1) Electrode Speed and Consumption Estimation

Based on this testing process using FCAW and SMAW welding using the Backing Ceramic method, there is an estimate of the speed and electrode consumption per specimen.

a) Flux Cored Arc Welding (FCAW)

TABLE IV. FCAW ELECTRODE CONSUMPTION PER SPECIMEN

Current (A)	Welding Speed (cm/min)	Electrode Consumption (kg)
100 A	12 cm/min	0.162 kg
120 A	14 cm/min	0.189 kg
140 A	16 cm/min	0.216 kg

Source: Based on the results of electrode consumption formula calculations and test results

b) Shielded Metal Arc Welding (SMAW)

TABLE V. SMAW ELECTRODE CONSUMPTION PER SPECIMEN

Current (A)	Welding Speed (cm/min)	Electrode Consumption (kg)

100 A	14 cm/min	0.189 kg
120 A	16 cm/min	0.216 kg
140 A	18 cm/min	0.243 kg

Source: Based on the results of electrode consumption formula calculations and test results

2) Electrode Consumption Development

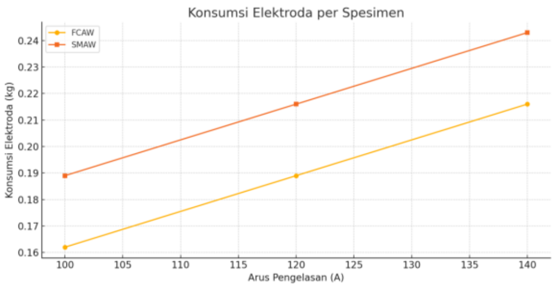

Fig 7. Electrode Consumption per Specimen

This graph shows the relationship between welding current (A) and the amount of electrode consumed (kg) in two welding methods, namely FCAW and SMAW. As the current increases from 100 A to 140 A, the electrode consumption in both methods increases. However, it can be seen that the SMAW method always consumes more electrodes than FCAW at each current level. For example, at a current of 100 A, the FCAW method requires about 0.162 kg of electrode, while SMAW consumes about 0.189 kg. This difference continues until a current of 140 A, where SMAW consumes more than 0.24 kg of electrode, while FCAW is still at around 0.216 kg.

From these data, it can be concluded that the FCAW method tends to be more efficient in electrode usage than SMAW, especially in welding with higher currents. This efficiency is certainly an important consideration in efforts to reduce material costs in the production process.

3) Calculation Details

In the process of calculating the welding costs, there is a detailed calculation formula for the costs, where in this problem the FCAW (Flux Cored Arc Welding) and SMAW (Shielded Metal Arc Welding) welding processes are used as follows:

TABLE VI. FCAW AND SMAW WELDING COST BREAKDOWN FORMULA

Type of Formula	Formula
Time	$\frac{\text{Panjang Las (cm)}}{\text{Kecepatan Las }(\frac{cm}{menit})}$
Power	$\frac{\text{Tegangan (V)} \times \text{Arus (A)}}{1000 \times \text{Efisiensi Mesin}}$
Electricity	Daya (kW) × Waktu (jam) × Listrik kWh (Rp)
Welder	Waktu (jam) × Upah
Electrode Consumption	$\left(\frac{\text{Konsumsi Elektroda (kg)}}{\text{Efisiensi}}\right) \times \text{Harga Elektroda/kg}$
Backing Ceramic	Panjang Pengelasan (m) × Harga per meter

D. *Welding Cost Comparison Analysis*

After carrying out the testing process and calculating the costs of the welding process that has been carried out, there are several calculation formulas used. The following is a calculation of the calculation of all costs for the welding process that has been carried out.

1) Flux Cored Arc Welding (FCAW)

The results of the calculations carried out in the previous stage can produce a calculation of the costs required to carry out the Flux Cored Arc Welding (FCAW) welding test with three welding currents, namely as follows

TABLE VII. TOTAL CALCULATION OF FCAW WELDING COST

Currant	Information	Result	Total
100 A	Electricity	Rp. 468	Rp. 23.718
	Welder	Rp. 3.750	
	Electrode Consumption	Rp. 13.500	
	Backing Ceramic	Rp. 6.000	
120 A	Electricity	Rp. 481	Rp. 25.441
	Welder	Rp. 3.210	
	Electrode Consumption	Rp. 15.750	
	Backing Ceramic	Rp. 6.000	
140 A	Electricity	Rp. 488	Rp. 27.278
	Welder	Rp. 2.790	
	Electrode Consumption	Rp. 18.000	
	Backing Ceramic	Rp. 6.000	
Total			Rp. 76.437

Based on the calculations according to the table above, it can be concluded that the welding process Flux Cored Arc Welding (FCAW) which uses three welding currents, namely 100 A, 120 A, 140 A has a cost of Rp. 76,437.00.

2) Shielded Metal Arc Welding (SMAW)

The results of the calculations carried out in the previous stage can produce a calculation of the costs required to carry out Shielded Metal Arc Welding (FCAW) welding tests with three welding currents, namely as follows:

TABLE VIII. TOTAL CALCULATION OF SMAW WELDING COST

Currant	Information	Result	Total

100 A	Electricity	Rp. 401	Rp. 27.057
	Welder	Rp. 3.210	
	Electrode Consumption	Rp. 17.446	
	Backing Ceramic	Rp. 6.000	
120 A	Electricity	Rp. 420	Rp. 19.148
	Welder	Rp. 2.790	
	Electrode Consumption	Rp. 19.938	
	Backing Ceramic	Rp. 6.000	
140 A	Electricity	Rp. 435	Rp. 31.355
	Welder	Rp. 2.490	
	Electrode Consumption	Rp. 22.430	
	Backing Ceramic	Rp. 6.000	
Total			Rp. 87.560

Based on the calculations according to the table above, it can be concluded that the welding process Shielded Metal Arc Welding (SMAW) which uses three welding currents, namely 100 A, 120 A, 140 A has a cost of Rp. 87,560.00.

3) Total Welding Cost Development

Based on the tests that have been carried out shows a comparison of the total welding costs between two methods, namely FCAW (Flux-Cored Arc Welding) and SMAW (Shielded Metal Arc Welding), at various welding current levels (A).

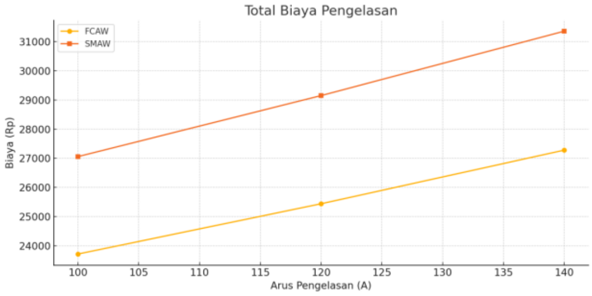

Fig 8. Total Welding Cost Graph

It can be seen that as the welding current increases from 100 A to 140 A, the costs incurred for both methods also increase. However, the trend of increasing costs in the SMAW method is higher than that of FCAW. For example, at a current of 100 A, the cost for the FCAW method is around Rp23,800, while SMAW has reached around Rp27,100. This gap continues to widen until the current of 140 A, where the cost of SMAW approaches Rp31,400, while FCAW is only around Rp27,300.

Based on these data, it can be concluded that the FCAW method tends to be more cost-effective than SMAW, especially at higher current levels. This information can be an important consideration in choosing an economically efficient welding method in the field.

V. Conclusion

Based on the research findings, it can be concluded that welding with the flux-cored arc welding (FCAW) method combined with backing ceramic is more efficient than the shielded metal arc welding (SMAW) method for welding ASTM A36 steel plates. Using FCAW can reduce welding time, which directly impacts operational costs, particularly labor and consumable material usage. Additionally, Backing Ceramic has proven effective in maintaining consistent welding results and minimizing defects, which typically require rework and increase production costs. Overall, FCAW with Backing Ceramic can be an efficient alternative for companies looking to reduce production costs without compromising the quality of welded joints.

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