ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun1706

Optimization of Flux Cored Arc Welding (FCAW) on Erection Joint Block Welding using Mechanized Automatic Welding

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Publication Date: 2025/07/03

Abstract: The competition in the shipyard industry is becoming increasingly intense, where more efficient processes are required not only to compete in terms of cost but also in the quality of the final product. Welding is a critical process in ship construction, where the quality of weld joints significantly affects the safety and durability of the ship's structure—especially in the welding of block joints (Erection Joint Block). Flux-Cored Arc Welding (FCAW) technology, besides improving productivity and reducing operational costs, enables the development of supporting technologies that reduce operator dependency and enhance the overall weld quality. Numerous studies have highlighted the influence of welding parameters such as current, voltage, and travel speed on joint quality, while the skill level of welders also has a significant impact on the quality of the weld. Given the large volume of welding tasks that must be completed simultaneously, the use of automated technologies such as Mechanized Automatic Welding (MOW) can be an effective solution.Therefore, this study aims to analyze the impact of technology and determine the optimization of FCAW welding on ship block joints using MOW technology. Experiments involved applying MOW in three flat position welding variants with alternatives: 100% welder, 100% MOW, and combinations of 80% MOW, 50% MOW, and 20% MOW. Experimental data were analyzed using the Analytical Hierarchy Process (AHP) with Expert Choice 11 to identify patterns and influences, followed by determining optimal alternatives and comprehensive solutions that meet the acceptance criteria for welding inspection. The results are expected to contribute significantly to the development of welding technology and enhance the competitiveness of the shipyard industry.

Keywords: *FCAW Welding, Mechanized Automatic Welding, Weld Quality, Erection Joint Block, AHP Expert Choice 11, Acceptance Welding.*

How to Cite: Wahyujaya Akhir Candra; Bagiyo Suwasono; Mochamad Zaed Yuliadi (2025). Optimization of Flux Cored Arc Welding (FCAW) on Erection Joint Block Welding Using Mechanized Automatic Welding. *International Journal of Innovative Science and Research Technology* 10(6), 2256-2270, https://doi.org/10.38124/ijisrt/25jun1706

I. INTRODUCTION

The shipbuilding industry plays a crucial role in supporting the global economy. One of the most essential aspects of ship construction is weld quality, which directly influences the structural integrity and safety of vessels. Welding defects such as porosity, undercut, and incomplete fusion can significantly weaken a ship's structure, posing safety risks and leading to costly repairs or failures [1]. As demand grows for faster and higher-quality ship production, welding parameters—such as current and voltage—have been shown to greatly affect the mechanical properties of welded joints [2]. Among various welding techniques, Flux Cored Arc Welding (FCAW) has emerged as a preferred method due to its speed and consistent weld quality [3]. However, the industry continues to face challenges, including a shortage of skilled welders and increasingly tight project deadlines. The quality of welds is still heavily influenced by operator skill and experience [4]. To overcome these limitations, welding automation technologies such as Mechanized and Orbiting Welding (MOW) have been developed to enhance productivity, improve consistency, and reduce operator dependence. Welding automation can increase productivity by up to 30%, making it a promising solution for shipyards facing manpower constraints [5]. The integration of MOW with FCAW can significantly shorten production cycles, reduce operational costs, and maintain high weld quality—making it particularly valuable for projects involving erection joint blocks in ship hull construction [6].

Previous studies have demonstrated the potential of combining FCAW with MOW to produce high-quality welds with minimal defects, but research gaps remain in optimizing parameters and adapting this integration to local shipbuilding environments. This research aims to address these gaps by exploring how MOW can be effectively implemented to enhance weld quality, efficiency, and overall competitiveness in the shipbuilding sector. The main objectives of this study are to develop an optimization method for FCAW that improves the weld quality of erection joint blocks and to design an efficient FCAW welding process using MOW technology. The findings of this research are expected to

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun1706

provide practical solutions for the shipbuilding industry and serve as a reference for further studies on automated mechanical welding and collaborative robotic (CoBot) applications.

This study is limited to welding work on erection joint blocks using FCAW in the flat position, incorporating ceramic backing. The volume of welding work is considered relatively uniform due to the consistent length of welds across blocks. Weld quality inspections are restricted to visual assessments using a standardized QC checklist, focusing on specific welding defects such as lack of fusion, porosity, undercut, low bead, and excessive reinforcement.

II. LITERATURE REVIEW

Flux Cored Arc Welding (FCAW) is a semi-automatic arc welding process that utilizes a continuously fed tubular wire filled with flux. The flux generates a shielding gas that protects the weld area from atmospheric contamination, making it suitable for outdoor and all-position welding. FCAW is widely adopted in the shipbuilding industry due to its ability to produce strong and durable joints efficiently. It offers high deposition rates and can operate under adverse environmental conditions, making it especially valuable for ship construction projects often conducted in open environments. The use of FCAW in block assembly can reduce production time by up to 30% compared to traditional methods. In addition to new ship construction, FCAW is also advantageous for ship maintenance and repair, particularly in hard-to-reach areas where conventional techniques are less effective.

The effectiveness of FCAW greatly depends on the control of critical welding parameters such as current, voltage, and travel speed. Incorrect current levels can lead to defects—low current results in poor penetration, while excessive current causes porosity or cracking. Likewise, excessive voltage may stabilize the arc but also evaporate protective flux, compromising weld quality. Improper travel speeds can result in overheating, undercut, or inconsistent weld beads [7].

Tensile strength and weld toughness are significantly influenced by parameter variation. Hence, optimizing these parameters is crucial for achieving desired mechanical properties [8]

To maintain weld consistency and quality, a Welding Procedure Specification (WPS) is essential. A WPS outlines standardized welding techniques and parameters tailored to specific materials, positions, and joint designs. It includes critical data such as base metal type, welding position, filler metal specification, and acceptable ranges for voltage and current. WPS plays a pivotal role in ensuring repeatability, meeting standards such as those established by the American Welding Society (AWS) or ISO. Standardized procedures minimize variation and serve as a documented reference during quality audits and inspections [9].

Equally important is the competency of the FCAW welder, which includes technical knowledge, practical skills, and a clear understanding of applicable codes and standards. A competent welder must understand arc characteristics, electrode classifications, and the impact of parameter adjustments. Practical competencies include joint preparation, slag management, and machine operation. Weld quality strongly correlates with operator expertise, structured training programs significantly boost both productivity and quality [10]. Furthermore, companies investing in welder upskilling achieved up to 40% reduction in weld defects, reaffirming the importance of continuous training in maintaining structural integrity in shipbuilding [11].

Mechanized Automatic Welding (MOW) is a semi-automated process where certain tasks, such as wire feeding and arc length control, are automated, while others—like torch manipulation—remain manual. This approach bridges manual skill with automated precision, improving productivity and reducing human error. MOW is adaptable to multiple processes, including MIG/MAG and FCAW. Mechanized welding offers cost-effective automation by reducing manual workload while maintaining high weld consistency. Robot-assisted welding systems in shipyards can boost productivity by up to 50% and significantly reduce production cycletimes.

Fig 1 Automatic Welding Mechanical Equipment

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The adoption of real-time welding monitoring systems further enhances process control. Real-time monitoring—using sensors to track voltage, current, and temperature—enables rapid corrective action during welding. These systems help in maintaining parameter accuracy and reducing defects. confirmed that real-time feedback mechanisms improve weld quality by enabling immediate parameter optimization. Case studies show that integrating monitoring technologies has led to defect reductions of up to 30% within a year, underscoring the synergy between automation, monitoring, and skilled operators in ensuring reliable weld outcomes in the shipbuilding industry.

III. METHODS

This study applies the Analytic Hierarchy Process (AHP) to determine the most optimal FCAW welding method for Erection Joint Block fabrication in shipbuilding. A welding simulation was performed on a flat-position joint using ceramic backing over a 1200 mm span, across three material thickness variants. Five welding alternatives were evaluated: fully manual welding (W 100), fully mechanized welding (MOW 100), and three hybrid variations (MOW 80, MOW 50, and MOW 20), each combining manual and automatic welding in different proportions. Visual inspection was used to assess welding quality based on common defects such as lack of fusion, porosity, undercut, low bead, and excessive reinforcement.

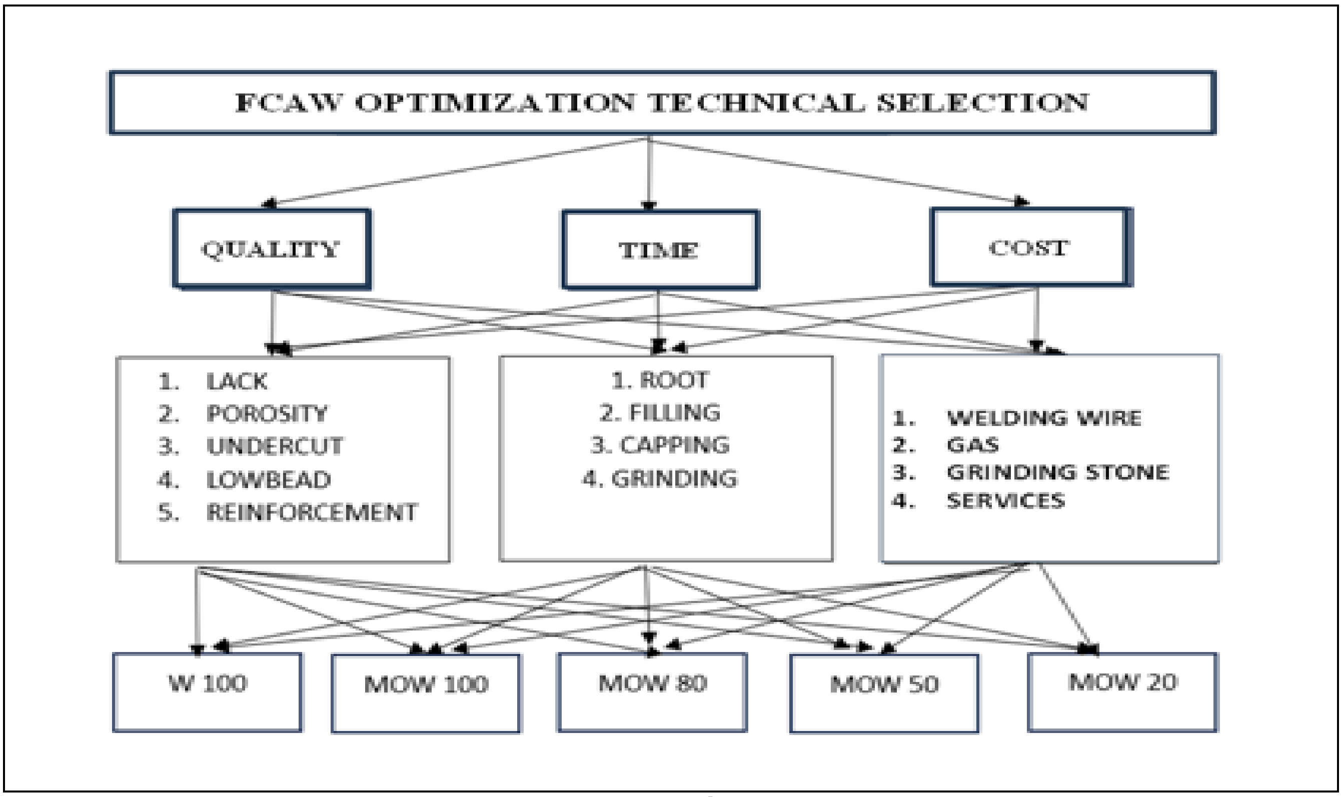

Fig 2 AHP Hierarchy Diagram

The decision criteria consisted of quality, time, and cost, and pairwise comparisons were conducted using Saaty's scale to determine relative importance. Unlike expert judgment approaches, scoring was based on empirical findings from welding trials, processed using Expert Choice 11 software. Simulation results were compiled into decision matrices and calculated using AHP to identify the best-performing alternative. This methodology supports data-driven decision-making to improve welding quality, efficiency, and cost-effectiveness in shipyard production environments.

IV. RESULTS & DISCUSSION

This study aims to optimize Flux Cored Arc Welding (FCAW) for Erection Joint Block welding in ship construction by utilizing Mechanized Automatic Welding (MOW) technology. In response to the limited number and varying competence of manual welders in the shipbuilding industry, mechanized welding is considered a strategic solution to improve weld quality, reduce processing time, and lower operational costs.

Experiments were conducted on three critical ship structure areas: Tank Top, Main Deck, and Upper Deck, each with a 1200 mm weld length. Five welding alternatives were tested:

- A: 100% manual welder (W100)
- B: 100% MOW (MOW100)
- C: 80% MOW and 20% welder (MOW80)
- D: 50% MOW and 50% welder (MOW50)
- E: 20% MOW and 80% welder (MOW20)

The results were analyzed using the Analytical Hierarchy Process (AHP) method through Expert Choice 11 software, focusing on three evaluation criteria: weld quality, processing time, and cost.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun1706

- *Tank Top Welding:*

Analysis shows that MOW 80 yields the most optimal results across all criteria. Common defects such as porosity and undercut were significantly reduced with semi-automatic welding.

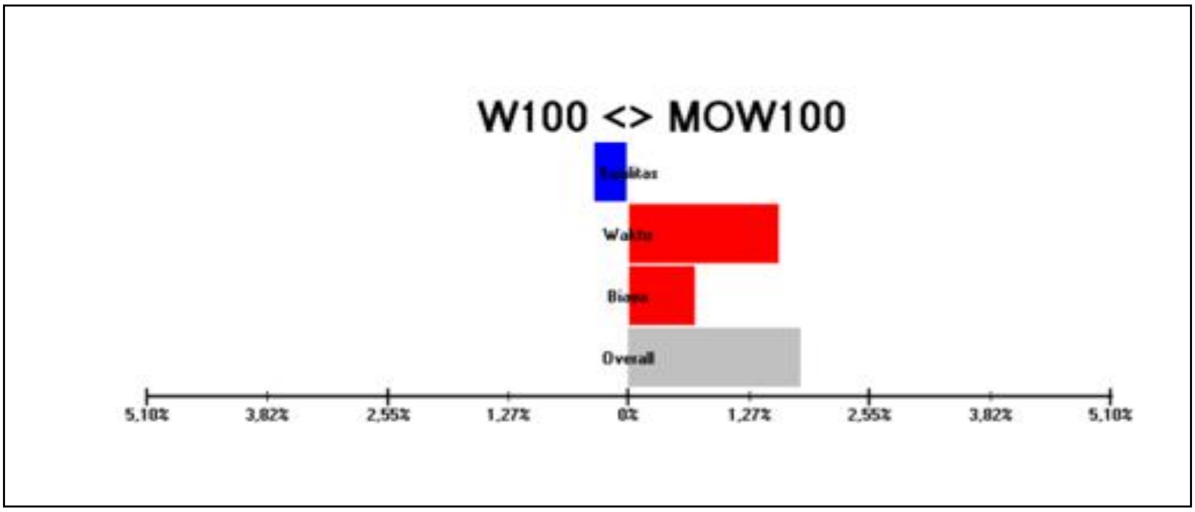

Fig 3 Head to Head Graph Results between Welder 100% and MOW 100% Welding on Tank Top

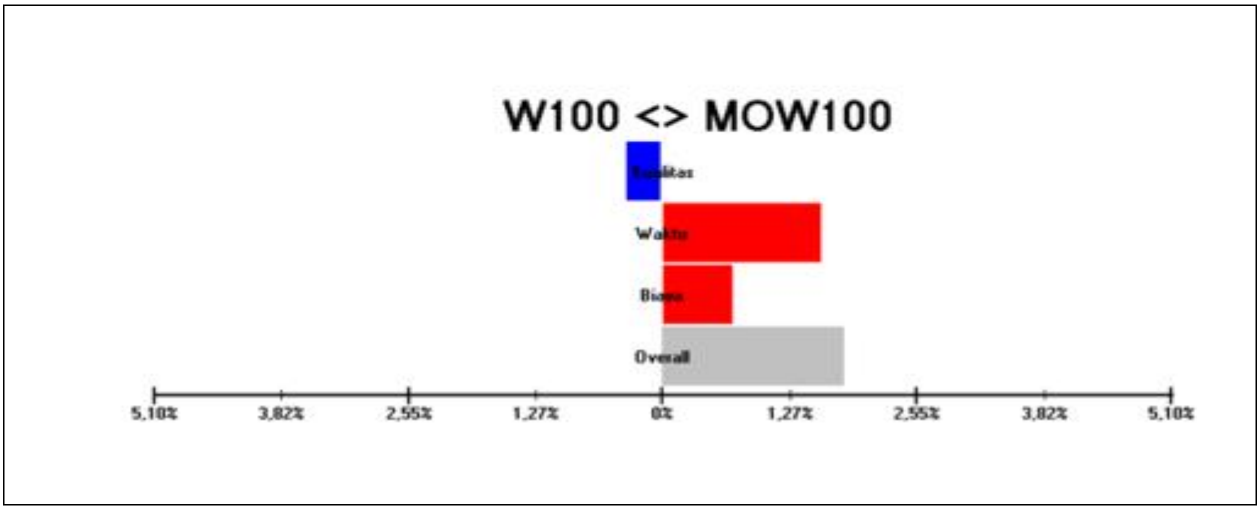

Fig 4 FCAW Tank Top Optimization Selection Goal Results

- *Main Deck Welding:*

MOW80 also performed best in Main Deck welding. No critical weld defects (such as lack of fusion or porosity) were observed. Additionally, MOW80 achieved the shortest welding time and favorable cost performance.

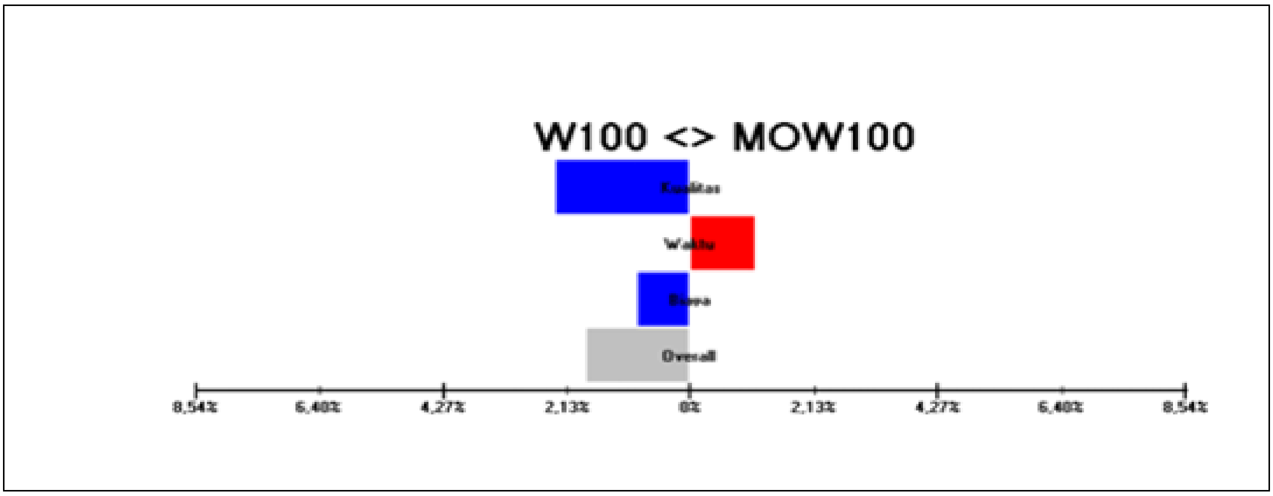

Fig 5 Head to Head Graph Results between Welder 100% and MOW 100% Welding on Main Deck.

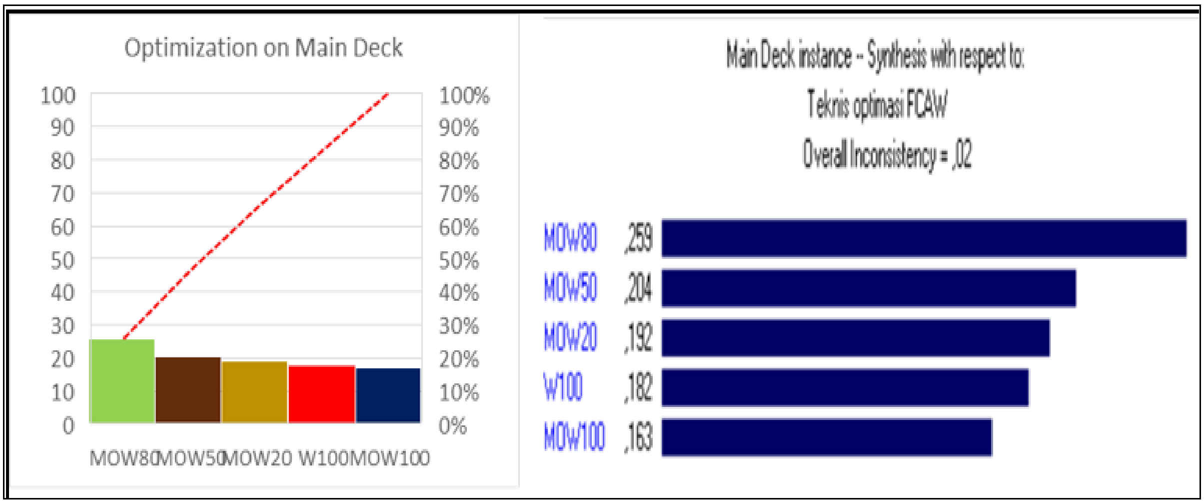

Fig 6 FCAW optimization selection goal results on Main Deck

➢ *Upper Deck Welding:*

For the thinner Upper Deck plate, the MOW80 configuration once again delivered superior results across all evaluation criteria. It achieved the highest weld quality with minimal defects, demonstrated efficient processing time throughout all welding stages, and maintained cost-effectiveness compared to other alternatives. These results reinforce the consistency and adaptability of the MOW80 method, even on thinner materials where precision and control are critical.

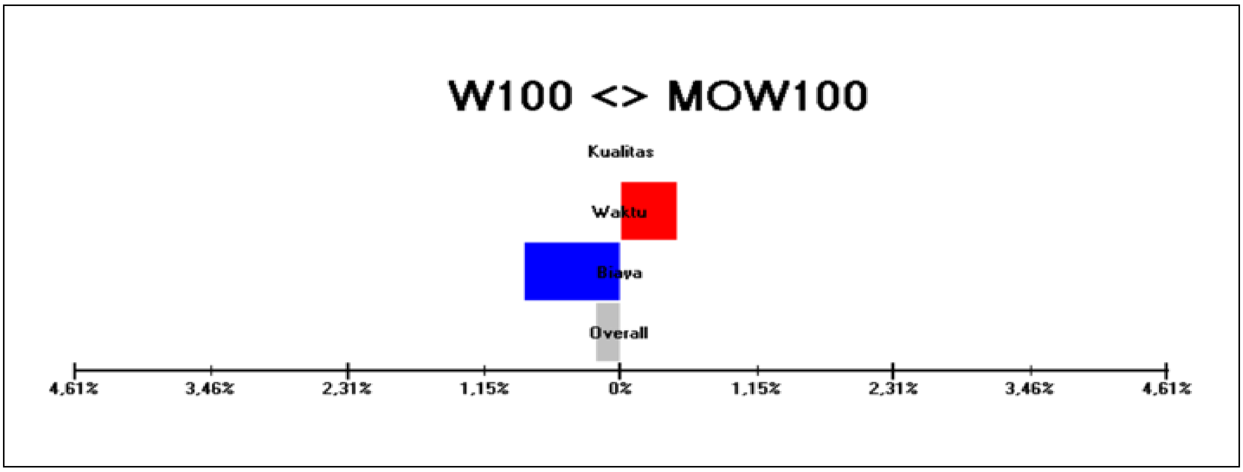

Fig 7 Head to Head Graph Results between Welder 100% and MOW 100% Welding on Upper Deck.

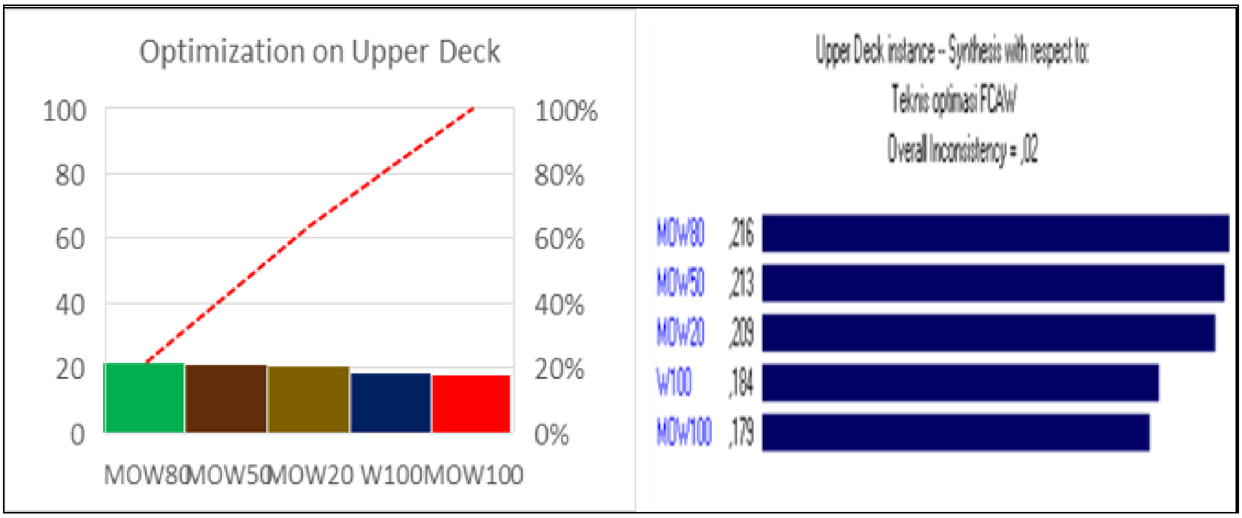

Fig 8 FCAW Optimization Selection Goal Results on Upper Deck

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun1706

➢ *Quality Criteria:*

Weld quality was assessed based on the occurrence of weld defects. The most frequent defect was reinforcement, followed by lack of fusion and porosity. The MOW80 alternative consistently minimized all types of defects.

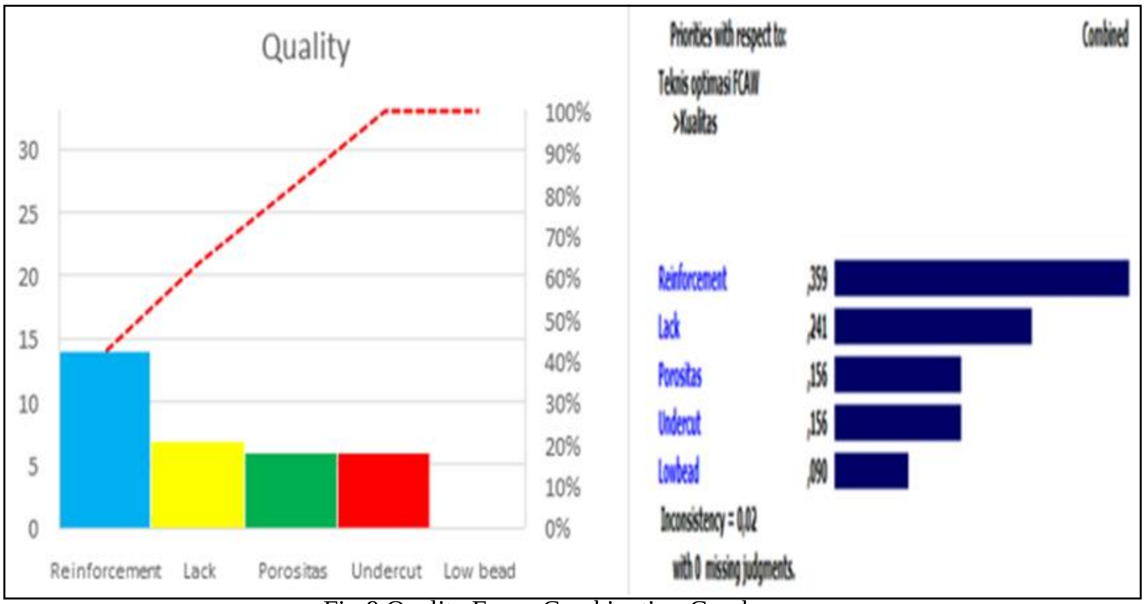

Fig 9 Quality Focus Combination Graph

➢ *Time Criteria:*

Welding time was broken down into key activities: root pass, filling, capping, and grinding. The MOW80 configuration demonstrated the highest time efficiency across all stages, especially for filling and capping, which were performed mechanically.

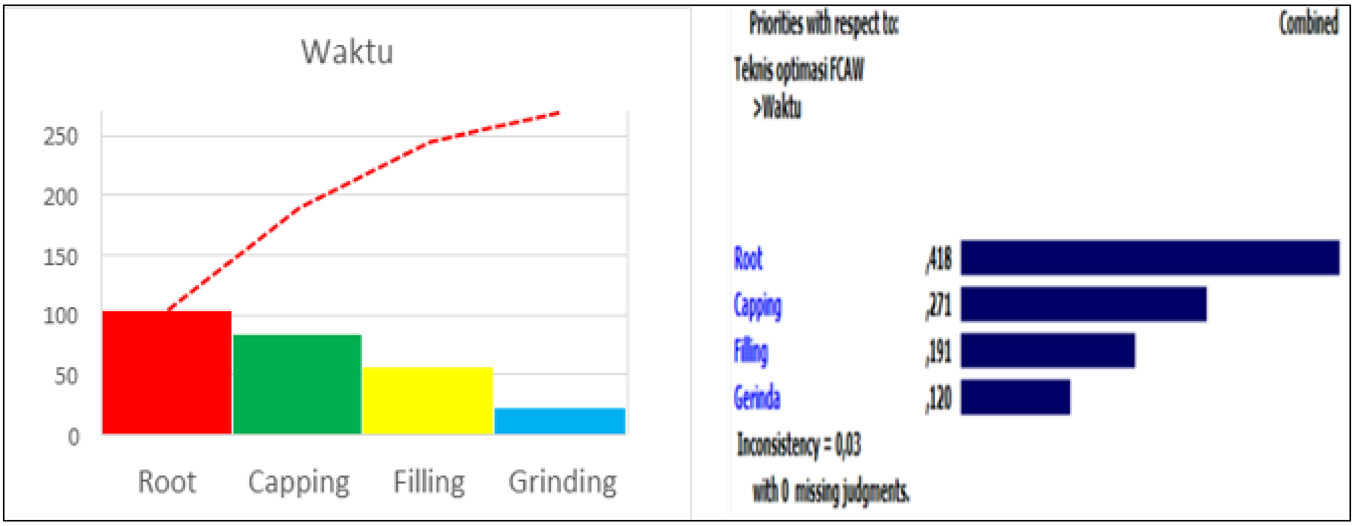

Fig 10 Time Focus Combination Graph.

➢ *Cost Criteria:*

From a cost perspective, MOW80 offered a balanced performance. Cost elements included welding wire, shielding gas, grinding tools, and labor. Processed data showed that MOW80 incurred lower total costs compared to alternatives relying heavily on manual labor.

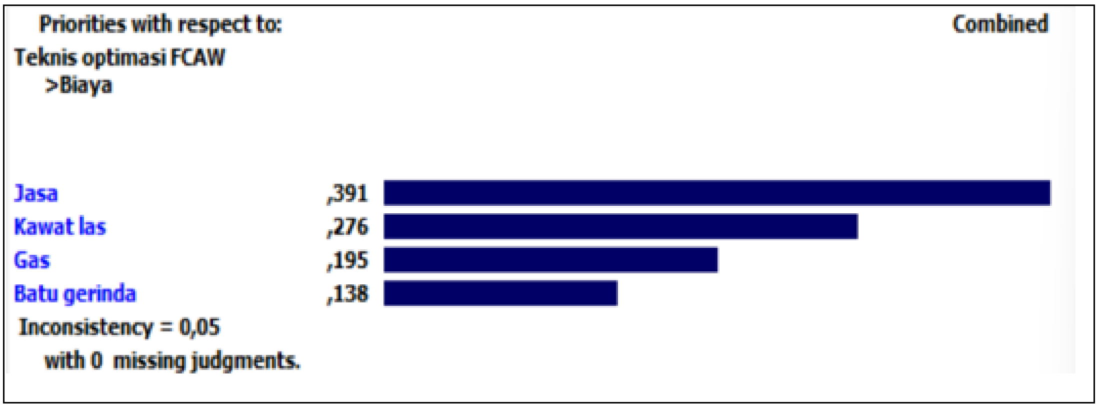

Fig 11 Cost Focus Combination Graph.

- *Performance Analysis and Alternative Comparisons:*

Head-to-head comparisons indicate that Alternative C (MOW80) has the highest overall performance score among all tested alternatives. In this configuration, the root pass is executed by a welder, while filling and capping are fully performed by MOW.

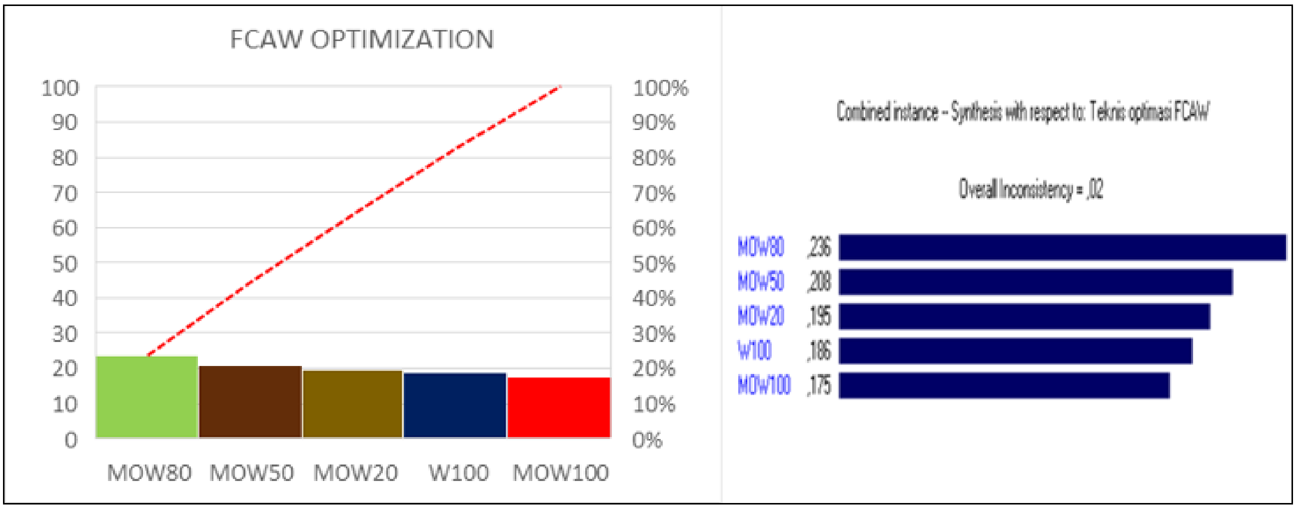

Fig 12 Combination Graph of FCAW Optimization Selection Goal in Erection Join Block welding

- *Simulation Scenarios and Sensitivity Analysis:*

To validate the robustness of the findings, five simulation scenarios were conducted by varying the weight of the evaluation criteria:

- Equal weight (33.3% Quality, 33.3% Time, 33.3% Cost)
- Quality-focused (50% Quality)
- Time-focused (50% Time)
- Cost-focused (50% Cost)
- Quality-focused with 10% sensitivity interval

Across all simulations, MOW80 remained the most optimal alternative, with the highest and most consistent performance scores.

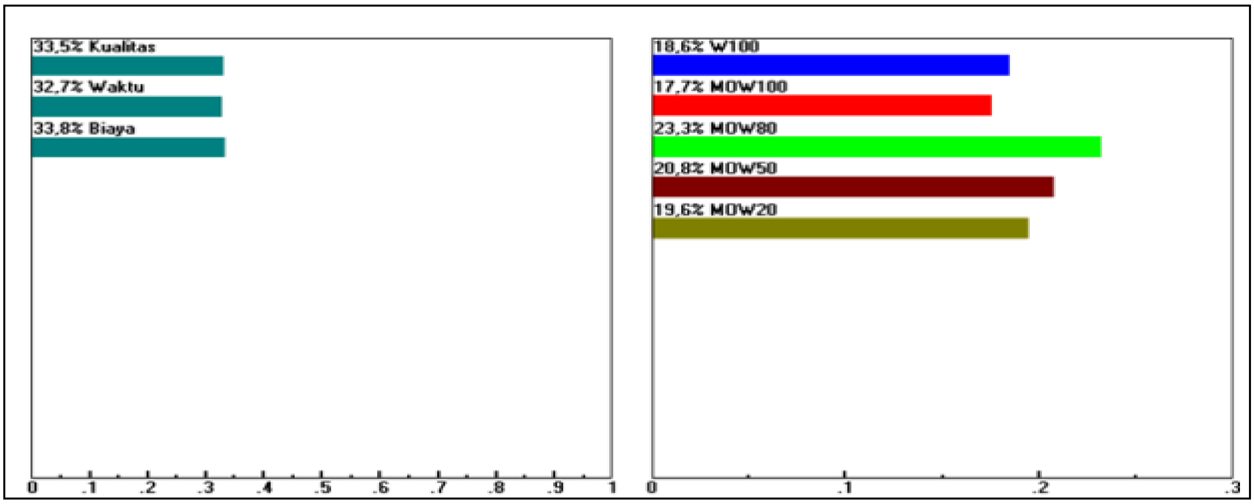

Fig 13 Dynamic Welding Graphic Results on Erection Join Block Simulation Equal Weight Criteria

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun1706

➢ *Key Conclusion:*

The most effective approach to optimizing FCAW for Erection Joint Block welding is the MOW80 collaborative model, combining 80% mechanized welding and 20% manual welding. This configuration reduces reliance on manual welders, accelerates the welding process, lowers costs, and ensures weld quality in compliance with acceptance standards. Implementing this model can significantly enhance efficiency and competitiveness in the national shipbuilding industry.

V. SUMMARY

The optimization of Flux Cored Arc Welding (FCAW) on ship block joints (Erection Joint Block) can effectively be achieved using Mechanized Automatic Welding (MOW) as a solution to the limited number and competence of welders. While welding quality is influenced by welder skills, it is not solely dependent on them. Through experiments, simulations, and data analysis using Expert Choice 11 software based on quality, time, and cost criteria, the most effective approach is a collaborative model between welders and MOW. The optimal result was found in Alternative C (MOW 80), with 80% MOW and 20% welder involvement. This configuration showed the best performance with a score of 23.6%, where root pass welding is performed by welders, while filling and capping are handled by MOW. Therefore, challenges related to quality, time, and cost in Erection Joint Block welding—and in shipbuilding more broadly—can be optimized through the use of MOW or more advanced collaborative robots (Cobots).

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