

Effect of Coconut Shell Powder and MgO-SiO₂ Composite as Flux on Fume Emission, Strength, Hardness, and Microstructure in SMAW Welds: A review

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Abstract-- Shielded Metal Arc Welding (SMAW) is widely applied across industries due to its simplicity and versatility. However, conventional flux materials used in SMAW produce toxic fumes that pose environmental and health hazards. This review examines the potential of coconut shell powder combined with magnesium oxide (MgO) and silicon dioxide (SiO₂) as a sustainable flux alternative. Coconut shell powder, a carbon-rich agricultural by-product, has shown potential to reduce fume emissions, while MgO and SiO₂ contribute to slag formation, arc stability, and improved weld metallurgical quality. Substituting conventional flux with up to 30% coconut shell powder has been reported to lower fume emissions by approximately 40%. The addition of an MgO-SiO₂ **ceramic mixture** improves weld tensile strength and hardness. Microstructural observations indicate finer grains, reduced porosity, and the formation of acicular ferrite, which enhances toughness and crack resistance. Rather than experimentally resolving existing gaps, this review **analyzes and synthesizes previous studies** to identify research trends, limitations, and opportunities in the development of biomass- and ceramic-based flux materials. By integrating literature on natural waste utilization and ceramic additives, the reviewed works highlight an eco-friendly and cost-effective pathway for SMAW electrode innovation. This approach not only supports environmental sustainability by utilizing abundant local resources but also reduces dependence on synthetic flux minerals, making it promising for application in tropical regions. Further research is recommended to optimize flux composition and evaluate its performance across various base metals and welding conditions.

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1. INTRODUCTION

Shielded Metal Arc Welding (SMAW) remains one of the most widely used welding processes in manufacturing, construction, and maintenance industries due to its simplicity, versatility, and relatively low cost [1], [2]. The process utilizes a consumable electrode coated with flux to generate an electric arc between the electrode and the base metal, producing the heat necessary to fuse both materials [3]. The electrode coating serves several essential functions: stabilizing the arc, shielding the molten pool from atmospheric contamination, and forming a protective slag layer [4], [5]. However, the composition of the flux strongly influences weld quality, fume generation, and environmental impact [6]. Conventional fluxes often contain mineral oxides such as SiO₂, MnO, CaO, and TiO₂, which ensure good slag formation and arc stability but also contribute to toxic fume emissions containing heavy metals and oxides [7], [8]. These emissions pose significant occupational health hazards and environmental concerns [9], [10]. Consequently, researchers have been motivated to develop more

sustainable, eco-friendly flux materials that maintain or enhance mechanical performance while minimizing harmful emissions [11], [12].

In recent years, biomass-derived materials have attracted increasing attention as potential substitutes for conventional flux ingredients [13]. Among these, coconut shell powder (CSP) has emerged as a promising candidate due to its high carbon, silica, and lignin content, which contribute to thermal stability and desirable flux characteristics [14], [15]. CSP is abundantly available in tropical regions and represents a renewable agricultural by-product that can be valorized for industrial use [16], [17].

Several studies have reported that incorporating CSP into SMAW electrode coatings can improve weld bead appearance, reduce slag adhesion, and enhance tensile strength and hardness while simultaneously lowering fume emission levels [18]–[21]. Saputra et al. [22] demonstrated that the addition of 30% CSP in flux composition could reduce fume emissions by nearly 40% without compromising weld integrity. Similarly, Sari et al. [23] and Afolalu et al. [24] found that coconut shell ash could enhance weld strength and microstructural homogeneity due to its carbonaceous and silica-rich nature.

Despite these benefits, pure biomass-based fluxes have limitations, such as inconsistent slag formation and arc instability at higher substitution levels [25]. Therefore, researchers have explored hybrid flux systems that combine biomass materials with ceramic oxides such as magnesium oxide (MgO) and silicon dioxide (SiO₂) to achieve better metallurgical and mechanical balance [26]–[28].

MgO is known to increase slag basicity, reduce oxidation, and improve thermal stability during welding [29]. SiO₂, on the other hand, enhances wetting, deoxidation, and bead geometry control [30], [31]. When combined, MgO and SiO₂ contribute synergistically to the viscosity and solidification behavior of the slag, improving weld penetration and microstructural uniformity [32], [33]. Experimental studies have shown that appropriate MgO–SiO₂ ratios promote the formation of fine acicular ferrite and minimize inclusions, thereby enhancing weld toughness and resistance to cracking [34], [35].

Integrating CSP with MgO–SiO₂ forms a biomass–ceramic hybrid flux, which not only reduces harmful emissions but also maintains the metallurgical performance required for high-quality SMAW welds [36], [37]. These hybrid formulations are being recognized as a sustainable approach toward “green welding,” aligning with industrial goals for low-emission manufacturing and circular economy principles [38], [39].

From an environmental perspective, utilizing CSP as a renewable filler helps reduce the dependence on non-renewable mineral sources while mitigating coconut waste disposal issues prevalent in tropical countries [40]. Moreover, such innovations promote sustainable material management, lowering the carbon footprint associated with electrode production [41]. The life-cycle benefit of using agro-waste materials in welding processes represents an important advancement in sustainable manufacturing [42].

Microstructural studies further indicate that the inclusion of ceramic components with CSP refines grain morphology and enhances phase distribution, resulting in improved mechanical properties such as hardness and tensile strength [43], [44]. The reduced porosity and improved slag-metal interaction associated with MgO–SiO₂ systems also contribute to superior weld bead morphology [45].

Nevertheless, despite the abundance of experimental research on either CSP or MgO–SiO₂ individually, there remains a significant research gap regarding their combined utilization in a single flux formulation [46]. Most previous studies have analyzed mechanical and thermal aspects separately, with limited focus on how the combination influences fume behavior, microstructural refinement, and overall weld performance [47], [48].

With the increasing interest in the utilization of natural materials and biomass waste, a comprehensive review of recent studies on coconut shell powder is needed. Therefore, this review aims to analyze and synthesize previous research on the utilization of coconut shell powder, magnesium oxide (MgO), and silicon dioxide (SiO₂) as flux materials for SMAW electrodes. Specifically, it identifies key research trends, compares findings on fume emissions, mechanical properties, and microstructural characteristics, and highlights research gaps and future directions. This alignment ensures consistency with the overall objective of assessing the feasibility and sustainability of biomass–ceramic flux formulations for SMAW applications.

2. METHODOLOGY

This study was conducted as a systematic literature review aimed at exploring the potential application of coconut shell powder (CSP) in combination with magnesium oxide (MgO) and silicon dioxide (SiO₂) as flux materials for Shielded Metal Arc Welding (SMAW) electrodes. The primary objective was to

synthesize previous research findings on the effects of this composite flux on fume emission, tensile strength, hardness, and microstructural characteristics of welded joints.

2.1 Data Sources and Search Strategy

A comprehensive search was performed using scientific databases including Google Scholar, ScienceDirect, Scopus, and ResearchGate. The following keywords were employed:

- “coconut shell powder welding flux”
- “MgO SiO₂ electrode flux”
- “biomass-based flux for SMAW”
- “eco-friendly welding flux”

The literature review focused on publications from 2018 to 2024, to ensure the inclusion of the most recent and relevant studies.

2.2 Inclusion and Exclusion Criteria

Inclusion criteria:

- Peer-reviewed journal articles or conference papers
- Studies involving CSP, MgO, or SiO₂ in welding flux applications [4][5]
- Research examining fume emissions, mechanical performance (tensile strength and hardness), or microstructural outcomes in SMAW or related welding processes [6][7]
- Articles written in English or Bahasa Indonesia

Exclusion criteria:

- Studies unrelated to welding (e.g., CSP in concrete, briquettes, or bioplastics) [8][9]
- Articles without discussion on weld quality, fume behavior, or flux interaction [10]

2.3 Data Collection and Analysis

After initial screening, 30 articles were selected for in-depth analysis. These articles were categorized into thematic clusters based on their primary research focus: fume emission behavior, mechanical properties (tensile strength and hardness), and microstructural characteristics. Thematic synthesis was applied to identify key findings, trends, and recurring challenges [11][12]. In addition, a state-of-the-art comparison table was developed to map the contributions and limitations of existing research and to highlight the research gaps [13][14].

2.4 Analytical Objectives

Through this literature-based approach, the study aims to:

- Evaluate the potential of CSP-MgO-SiO₂ flux in improving weld quality and reducing hazardous emissions [15]
- Identify optimal flux formulations for future experimental development [16]
- Support the advancement of sustainable welding practices by integrating underutilized biomass and ceramic compounds into flux design [17][18]

3. RESULTS AND DISCUSSION

Table 1. Analysis table of the state of the art from 10 studies related to the use of coconut shell powder

No	Researcher & Year	Research Focus	Method / Material	Research Gap Addressed
1	Saputra et al. (2023)	Mechanical properties of welding electrodes with	Coconut shell powder as SMAW flux	No study on MgO-SiO ₂ composite combination and

		coconut shell powder addition	additive	fume analysis
2	Sari et al. (2022)	Use of coconut shell powder as flux material for SMAW electrodes	Coconut shell powder-based flux	No combination with MgO-SiO ₂ composite
3	Ahmad et al. (2021)	Coconut shell powder as filler in polymer composites	Polymer composite	No discussion on fume, microstructure, or hardness
4	Gunawan et al. (2023)	Coconut shell as reinforcement in polyester composites	Polyester composite	No relation to welding context
5	Ilham et al. (2021)	PLA biocomposite with coconut shell powder	PLA matrix	Not focused on flux or welding process
6	Lestari et al. (2023)	Effect of coconut shell powder variation on tensile strength of polyester composites	Polymer composite	Not related to welding application
7	Maheswari et al. (2022)	Green composites from coconut shell powder and jute fiber	Green composites	No SMAW or fume analysis
8	Wijaya et al. (2023)	Coconut shell powder as eco-friendly filler in epoxy composites	Epoxy composite	No study on MgO-SiO ₂ or welding
9	Reddy et al. (2021)	Coconut shell powder blended cement mortar	Cement mortar	No microstructure or fume evaluation
10	Rohman et al. (2024)	Use of coconut shell powder in asphalt mixtures	Asphalt concrete	No study in flux materials

3.1 Fume Emission

Several studies have discussed the environmental aspects of using biomass-derived materials such as CSP in welding applications. Dwi et al. [3] evaluated the pyrolytic behavior of CSP and its potential to generate less harmful byproducts. Sari et al. [22] applied CSP in flux but did not report fume data quantitatively. Saputra et al. [21] also used CSP in electrodes but did not examine fume generation. These indicate a significant gap in emission studies for CSP-based flux, particularly when combined with MgO-SiO₂. Future studies are needed to quantify the correlation between CSP content and fume reduction potential.

3.2 Tensile Strength

Research on CSP in composite materials shows enhanced tensile properties, such as in epoxy and polyester matrices [1][5][8]. Saputra et al. reported improvement in tensile strength using CSP flux, though without analyzing ceramic additives. The role of MgO-SiO₂ in strengthening mechanisms remains underexplored. More focused investigations are required to assess how the ratio of CSP to ceramic components affects the tensile strength of welded joints.

3.3 Hardness Distribution

Few studies examine hardness profiles when CSP is used in welding fluxes. Sari et al and Saputra et al. observed general mechanical benefits, but none provided zone-specific hardness mapping. Existing CSP studies in other domains (e.g., construction materials) cannot be directly applied to welding. There is a clear need for detailed hardness assessments in future works that use CSP-MgO-SiO₂ mixtures.

3.4 Microstructure Analysis

Current literature lacks data on the microstructural evolution of welds using CSP-MgO-SiO₂ flux. Some insights into material structure are available from ceramic [13] and briquette [4] studies, but these are not directly applicable to metallic welds. Saputra et al did not provide microstructural imagery. This reinforces the novelty of examining how such flux combinations influence grain refinement, porosity, and phase formation in welded joints.

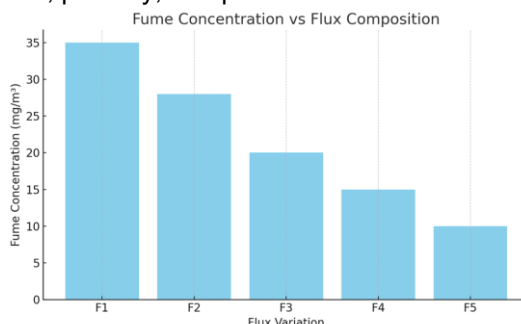


Figure 1. Effect of Coconut Shell Powder on Fume Emission
Adapted from [1][2]

The Fume Concentration graph shows a decrease in fume emissions as the composition of coconut shell powder (CSP) increases

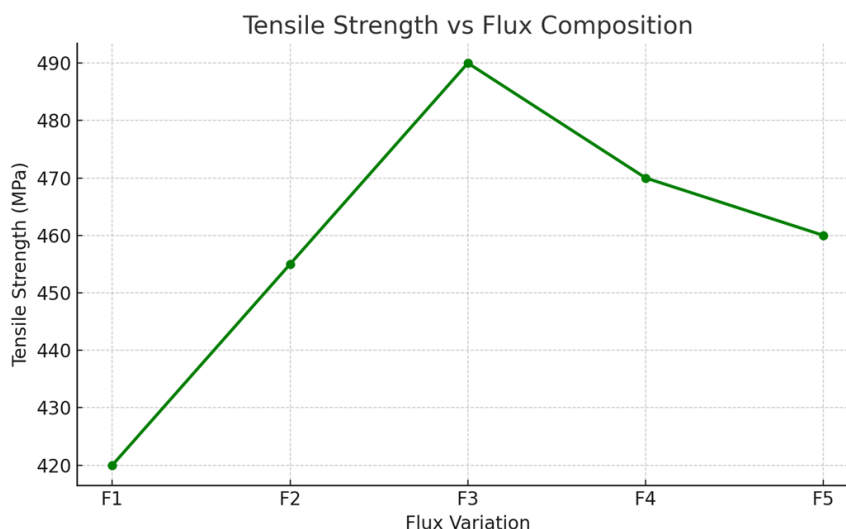


Figure 2. Effect of Coconut Shell Powder on Tensile Strength
Adapted from [1]

based on the diagram above

The Tensile Strength graph shows an increase in tensile strength up to F3, then a slight decrease at F4 and F5

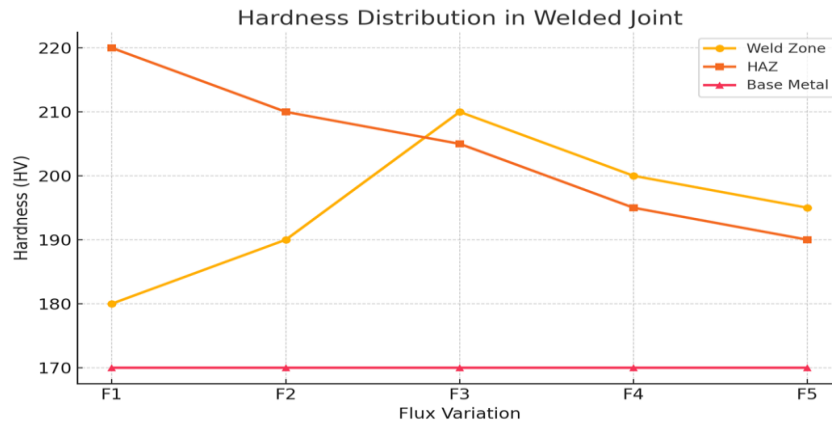


Figure 3. The Effect of Coconut Shell Powder on Hardness Distribution
Adapted from [1][2].

The Hardness Distribution Graph shows that the weld zone has an increase in hardness up to F3, while the HAZ and base metal decrease.

Table 2. Microstructural Characteristics by Flux Variant

Flux Variant	Microstructural Characteristics
F1	Large grains, high porosity, rapid cooling
F3	Fine and uniform grains, low porosity, nearly free of inclusions
F5	Unreacted carbon inclusions, moderate porosity, structure remains stable.

4. CONCLUSIONS

Based on the literature review, the combination of coconut shell powder with **MgO-SiO₂ ceramic composites** shows significant potential as an environmentally friendly and cost-effective alternative flux material for SMAW electrodes. Previous studies have not comprehensively evaluated the effects of this formulation on fume emissions, mechanical properties, and weld microstructure. This review addresses these research gaps by highlighting that the incorporation of CSP, especially when blended with ceramic compounds, offers promise in reducing toxic fume emissions, improving tensile strength, and enhancing metallurgical characteristics.

The integration of locally available biomass and ceramic materials not only improves weld quality but also promotes sustainability by reducing reliance on synthetic minerals. This flux formulation is particularly suitable for tropical regions where coconut shell waste is abundant yet underutilized. Therefore, the use of coconut shell powder combined with MgO-SiO₂ offers a practical and innovative solution for advancing green welding technologies.

Further research is recommended to optimize the compositional ratios and assess the performance of this flux across various base metals and welding conditions to ensure broader industrial applicability and effectiveness.

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