Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

Agrowaste-Derived Biomaterials for Sustainable Underwater Welding Electrodes: A Review

[1]Ayuba Elkanah Jatau, [2]Isah Muhammad, [3]Elkanah Bagudu Samuel

[1,2]Department of Mechanical Engineering, School of Infrastructure, Process Engineering and Technology, Federal University of Technology Minna, Niger State, Nigeria

[1]Department of Mechanical Engineering, Niger State Polytechnic Zungeru, Niger State, Nigeria

[3]Department of Welding Engineering and Offshore Technology, Petroleum Training Institute, Effurun, Delta State, Nigeria

Abstract: Underwater welding is essential for marine infrastructure maintenance, but wet-arc processes suffer severe weld defects due to water vapor dissociation and high hydrogen levels in the weld pool. Conventional electrodes (rutiles, basic fluxes) still generate high diffusible hydrogen and hard HAZs, limiting weld quality. As a sustainable alternative, this review examines agrowaste-derived biomaterials (rice husk, bagasse, coconut shell, corn stover, banana peel, etc.) as flux and coating components for underwater welding electrodes. We compare the feedstock chemistry (lignocellulose, ash/minerals) of each biomass, the conversion processes (pyrolysis, activation, pelletizing, sintering, binder selection), and electrode formulations proposed in recent studies. The review summarizes welding performance data (mechanical strength, hardness, H_2 content, porosity) for bio-flux electrodes versus conventional fluxes. It also analyzes arc stability and metallurgical effects: how carbonaceous slag and K/Ca silicates from biomass influence the arc and mitigate hydrogen ingress. Environmental and economic impacts are assessed through preliminary life-cycle analysis, highlighting carbon footprint reductions and cost savings from using waste biomass. Finally, we identify critical research gaps in welding metallurgy such as hydrogen entrapment, slag-metal reactions, material processing (scale-up of biochar electrodes), and regulatory issues. This review provides a comprehensive roadmap for developing sustainable underwater welding electrodes from agrowaste, to maintain weld quality while reducing environmental impact.

Keywords: Underwater welding; welding electrodes; biomass flux; agrowaste; biochar; hydrogen embrittlement; arc stability; life-cycle assessment; sustainable materials.

Highlights:

i. Agro-waste fluxes (rice husk, bagasse, etc.) enable lower carbon footprint and partial mineral replacement in marine welding electrodes.
ii. Biomass biochar adds organic content that stabilizes the underwater arc and can reduce weld hydrogen compared to purely mineral flux.
iii. Published formulations (e.g. palm kernel shell, date seed fluxes) show comparable tensile/impact performance to commercial electrodes while improving sustainability.
iv. Detailed tables of feedstock chemistry, electrode recipes, and welding test data summarize the state-of-art comparisons.
v. Identified future needs: optimizing biochar activation, binding agents, arc-slag-metal reactions, and full LCA for commercialization.

I. Introduction

Underwater welding is an indispensable process for inspection, maintenance, and repair of marine structures (offshore platforms, pipelines, ships, dams). It is uniquely challenging because the welding arc must burn underwater. In wet welding, the diver applies a standard arc electrode directly in the water. The arc's heat vaporizes the surrounding water, forming a gaseous envelope ("bubble") around the arc[1]. This bubble composition is unusual: roughly 70% hydrogen (H_2), 25% carbon dioxide, and 5% carbon monoxide[2]. The hydrogen, in particular, has two adverse effects: it diffuses into the hot weld metal, causing hydrogen embrittlement and cold cracking[3], and it expands in the solidifying metal, causing porosity[4]. For example, weld deposits from rutile electrodes (rich in TiO_2) can contain up to $100\ ml$ H_2 per $100g$ of deposited metal far higher than in dry welding[3]. Even "oxidizing" fluxes produce 25 ml/100 g. The hydrogen level increases with depth and arc power, so deep or

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

high-energy welds are at greater risk[5].

The wet welding environment also causes arc instability and defective slag protection. The cold surrounding water quickly quenches weld metal and slag, resulting in a narrow bead shape and incomplete slag coverage. Water currents and bubbles disturb the arc, increasing spatter and defects like blowholes. Moreover, rapid cooling raises the hardness of the heat-affected zone (HAZ) above safe limits, leading to brittle welds. In practice, welds made in wet conditions often fail to meet quality standards (e.g. CLASS A marine welds) unless special measures are taken (low heat input, preheating, peening).

To address these issues, the electrode flux chemistry and coatings are critical. A flux coating must generate a stable gas shield (bubble), facilitate smooth arc, and produce a protective slag. Traditional underwater MMA electrodes use a waterproofed flux: the flux is wetted with a hydrophobic binder so that it repels water until burned off. Flux ingredients include TiO_2 (rutile), CaF_2, CaO, alkali silicates, iron powder, cellulose, etc. Different classes of electrodes (rutile, basic, cellulose) have different flux chemistry and resulting weld properties. In brief, rutile electrodes (TiO_2-rich) give a smooth arc and CO_2 shielding gas, but still contain some cellulose which yields up to ~25 ml H_2/100 g in the weld. Cellulosic electrodes (pure wood-flour flux) burn to H_2/CO_2, producing even more hydrogen (~30–45 ml/100 g) but a very deep "punching" arc. Basic electrodes (CaF_2, lime) produce CO_2 and basic slag, minimizing hydrogen generation but requiring skilled control. Table 1 summarizes the key flux components and shielding gases for these types.

Despite decades of incremental improvements (e.g. adding iron powder, optimizing rutile/basic blend), conventional electrodes cannot fully eliminate hydrogen or achieve pristine welds underwater. Moreover, many flux minerals (CaF_2, TiO_2, ferroalloys) are costly, energy-intensive mined resources with large environmental footprints. In parallel with these challenges, there is rising interest in sustainable materials. Biomass waste streams (agricultural residues, food waste) are abundant and underutilized. Many contain high carbon and metal contents (K, Ca, Si) that can contribute to flux functions. Recent work has shown that agro-waste derived materials (palm kernel shells, date seeds, banana peels, rice husks, etc.) can be converted into welding flux powders that perform comparably to conventional fluxes on steel joints. This review examines the promise and challenges of using agrowaste-derived biomaterials in underwater welding electrodes.

We will survey (a) conventional underwater welding methods and flux chemistry; (b) relevant agrowaste types and their chemistry (cellulose, lignin, ash); (c) processing routes to make electrodes (biochar production, mixing, binders); (d) welding metallurgy – arc stability, hydrogen behavior, microstructure; (e) welding performance (mechanical tests, H-content, corrosion); (f) environmental and LCA impacts; and (g) research gaps and commercial prospects. Our goal is a comprehensive, journal-quality review that guides future development of environmentally friendly underwater welding electrodes.

II. Underwater Welding Technologies

Underwater welding falls into two main categories. In dry chamber (hyperbaric) welding, a sealed enclosure is flooded with gas and maintained at ambient pressure, allowing nearly air-like conditions[6]. Dry welding yields high-quality welds, but the expensive hyperbaric habitat limits its use to new construction or repair of critical components[7]. The more common and urgent approach is wet welding, which is done directly in water without a containment. Wet welding is simpler and quicker, requiring only hand-held or semi-automatic MMA or FCAW equipment. Its main advantage is convenience and lower cost, but at the expense of weld quality.

Figure 1 illustrates a typical wet welding setup: the diver/welder wears insulating gloves and holds a specially coated electrode. When the circuit is energized, the arc ignites and immediately vaporizes a cavity in the water. The resulting bubble envelops the arc and weld pool, providing a gas shield. The arc in water is a highly chaotic plasma column: high pressure (up to 10 atm per 10 m depth) and cooling by water lead to a constricted, shimmering arc. Studies (e.g. Guo *et al.*) have shown that the weld bead underwater is often only 60–70% the width of an identical bead in air, due to arc compression by surrounding water. The bubble is not static: pressure pulses and buoyancy cause it to oscillate, which can disturb arc stability. Bubble collapse can introduce additional oxygen and spatter. All of these fluid-dynamic effects contribute to arc voltage/current oscillations that complicate process control.

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

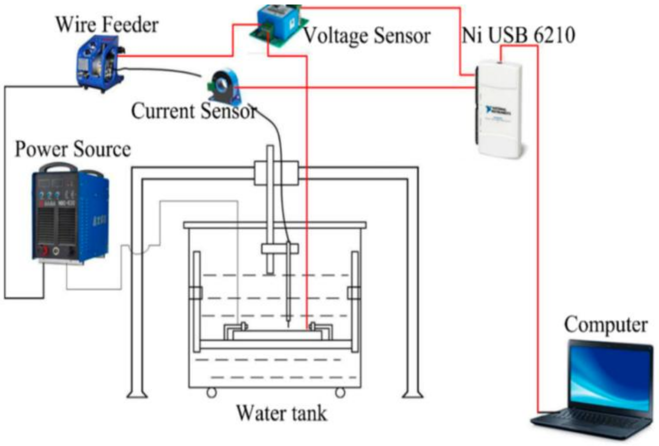

Figure 1: Schematic diagram of underwater wet welding system 8

In Figure 1**,** the welding system consists of a constant-current power source connected to a wire feeder, which continuously supplies the coated electrode into the weld zone inside a controlled water tank. A current sensor and a voltage sensor are integrated into the circuit to monitor the real-time welding current and arc voltage, providing essential information on arc stability and heat input throughout the welding process. These signals are transmitted to an NI USB-6210 data acquisition (DAQ) module, which digitizes the electrical parameters and transfers them to a computer for real-time monitoring, recording, and analysis. The acquired data are subsequently used to evaluate the influence of the agrowaste-derived electrode coating on welding performance, including arc stability, electrical characteristics, heat generation, and the overall quality of the underwater weld, thereby enabling a direct comparison with conventional welding electrodes.

The hydrogen formed by water dissociation is perhaps the greatest metallurgical issue. Weld metal diffusible-H must be controlled (<5–10 ml/100 g) to prevent cold cracks, but wet welding typically deposits over 20–50 ml/100 g even with "low-H" flux coatings[9]. Moreover, once trapped in a rapidly cooled weld, hydrogen can form microblisters or enhance HAZ hardness. Researchers have linked welding voltage, current, and metal transfer modes to the amount of trapped H in UWW welds[8]. It is well established that higher weld currents and slower travel speeds (i.e., more heat input) yield lower hydrogen levels[10], presumably by expanding the bubble and allowing more complete combustion of water vapor[10]. However, productivity pressures often lead to high heat inputs, so flux development to bind or neutralize H is crucial.

Other challenges include porosity and inclusions[11,12]. Rapid solidification can trap gas bubbles, and the turbulent pool can draw in fine slag or oxide particles[12]. Out-diffusion of CO from the bubble can also form pores. These defects degrade fatigue life and fracture toughness of underwater welds [13]. Thus, an ideal underwater electrode must simultaneously stabilize the arc, produce a clean molten pool, filter hydrogen, and form a tough weld metal a tall order for any flux formulation.

Recent advances in technology partly address these issues. For example, Han suggested that Mechanized flux-cored arc welding (FCAW) with "water curtain" or wire-brush shielding can lower porosity[14]. Additives like colloidal graphite, polymers, or exothermic powders have been tested to improve welding appearance and penetration[15–17]. Laser and friction-based processes are emerging for limited cases. Nevertheless, the electrode itself remains central, and any new flux chemistry (e.g. biomass-derived) must be evaluated in the context of these arc physics and metallurgical constraints.

III. Conventional Underwater Welding Electrodes

Modern manual underwater electrodes are adaptations of air electrodes with special flux coatings. They typically follow AWS classifications (e.g. E6013, E7018), but with hydrophobic binders (water-repellent oils, waxes) and additional arc stabilizers. Table 1 compares the major classes. Rutile electrodes (TiO_2) are widely used for wet welding due to their smooth arc and easy slag removal. Rutile flux contains mostly TiO_2 with minor cellulose; it burns to CO_2, but the embedded cellulose/moisture still yields ~10–25 ml H_2/100 g. Example*:* E6013 has K_2O, rutile, iron powder; produces quiet arc, some hydrogen[18]. Basic electrodes (CaF_2, CaO, ZrO_2) generate more basic slag and slightly lower hydrogen (tens of ml H_2) but tend to be more difficult to start[19,20]. Cellulosic electrodes (E6010, E6011) contain >30% wood-flour[21]; they burn to H_2/CO_2 gas and create a "punchy" penetrating arc, but produce very high weld-H (30–45 ml/100 g). These are less common underwater due to cracking risk, but useful in vertical-down position[22].

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

Table 1: Typical flux constituents and gas products for underwater MMA electrode

Electrode type	Flux components	Shielding gas products	Typical H_2 in weld (ml/100g)	Ref
Rutile (e.g. E6013)	TiO_2 (titania), little cellulose, basic oxides	Mainly CO_2	~10–25	[23]
Basic (e.g. E7018)	CaF_2, CaO, ZrO_2, alkaline silicates, minimal organics	CO_2 and CO	Low (often <10 ml)	[24]
Cellulosic (E6010/11)	Cellulose (wood-flour), charcoal, silicates	$H_2 + CO_2 + CO$	30–45	[19,21]

In practice, most commercial wet-electrodes are rutile-based or low-H basic types, sometimes with mixed top-layer adhesives or polymers to improve wetting[25]. The flux also contains iron powder (to adjust melt rate) and manganese/vanadium oxides (deoxidizers)[26]. These flux chemistries were developed empirically over decades, but they share common elements: CaO/SiO_2 glass formers[27], Ti/Zr oxides for arc stabilization[28,29], fluorides for slag fluidity[30]. The drawback is that TiO_2 and fluorite are expensive minerals with energy-intensive processing. Furthermore, wet-arc welding often requires higher currents (~150–300 A) and voltages (~50–70 V) to keep the hydrogen at bay, which also raises power consumption.

Because hydrogen embrittlement is the main failure mode, much effort has focused on reducing diffusible hydrogen. Coating formulations include iron powder and rutile to “soak up” hydrogen; coatings are dried at high temperature to drive off moisture. Still, reported H2 in wet welds typically exceeds 20 ml/100 g unless extra precautions (preheating, peening) are used[31]. More recently, novel fluxes for underwater welding have been patented, including halogen-free fluxes for wet soldering and resin-based binders. However, agrowaste-derived carbon materials have not yet been widely adopted in conventional wet electrodes, despite their obvious potential as low-cost carbon/lignite sources.

IV. Agrowaste Biomaterials: Feedstock and Properties

Agrowastes (agricultural and food processing residues) are an attractive source of lignocellulosic biomass. They are renewable, often abundant byproducts (sometimes 10–50% of crop weight), and currently underutilized. Key examples considered for welding flux include rice husk, sugarcane bagasse, coconut shell, corn stover, and banana peel. These materials vary in their chemistry:

i. Cellulose/Hemicellulose/Lignin

Most plant wastes are 70–80% combined cellulose, hemicellulose, and lignin, which provide fixed carbon and combustible content[32]. Typical values (dry basis) are: bagasse ~42%[33], cellulose, 25% hemicellulose, 25% lignin; corn stover ~37%, 20%, 17%; banana peel ~18–59% cellulose, 17–20% hemicellulose (rich in soluble sugars and pectin as well). Lignin is high in woody shells (coconut ~30–50% lignin, lower cellulose) and lower in peels[34,35].

ii. Ash and Minerals

Organic wastes also contain inorganic ash (as oxides of Si, Ca, K, P, etc.). Rice husk is notable: its ash is ~15–20% of mass[36], ~80–90% silica (SiO_2), making it the highest-silica biomass. Bagasse and stover have low ash (~2–8%) with common plant nutrients. Coconut shells can contain 1–2% salts but high lignin[37]. Banana peels are rich in potassium salts and Mg/Ca (ash ~10%. [38]These minerals affect the melting and viscosity of the resulting biochar/slag: silica and alumina raise melting point, whereas K_2O and CaO increase basicity and fluidity.

iii. Physical Form

The raw wastes also differ physically. Bagasse and rice husk are fibrous and bulky[39,40]; coconut shell is dense hard shell[41]; banana peel is soft and rich in pulp[42]. Before use, materials are typically dried and ground. For example, rice husk might be milled to <1 mm to homogenize, while coconut shell is crushed and sieved. High moisture or dirt must be removed to avoid pore-generating

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

volatiles. We summarize key feedstock compositions in Table 2. These values guide the choice of *which agrowastes make the best flux fillers* for underwater electrodes. For instance, rice husk (with high silica) can act like SiO_2 flux, while sugarcane bagasse (high fixed carbon) can boost carbon content and introduce K_2O.

Table 2: Selected compositions of agro-waste feedstocks (dry basis). Data compiled from literature.

Feedstock	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Notable Elements	Ref
Rice Husk	~35–40	15–20	20–25	15–20 (mostly SiO_2)	Si, K, Na, Ca (from ash)	[43]
Sugarcane Bagasse	~42.3	~25.1	~24.7	~3–4	K_2O, CaO, P_2O_5	[42–44]
Corn Stover	~36.9	~20.4	~17.4	~2–8	SiO_2 (varies), Ca, K	[45,46]
Coconut Shell	~20–30	~15–30	~50 (very high)	~1–2	$CaCO_3$, Mg, C (char)	[41]
Banana Peel	~18–59	~17–20	~<20	>10 (K-rich)	K_2O, Mg, P_2O_5	[47]

(*Notes:* Wide ranges reflect variety and measurement methods. Banana peel lignin typically 5–20%. Coconut lignin ~30–50%.)

These biomasses can be thermally processed to produce biochar or activated carbon. Pyrolysis at 400–800 °C (in N_2) converts the cellulose/hemicellulose to fixed carbon (~70–80% of original) and volatiles. For example, sugarcane bagasse yields ~30% biochar by weight (rest is syngas/tars). The resultant biochar retains much of the feedstock ash (so rice husk biochar is still extremely silica-rich). Activation (steam or KOH treatment) can greatly increase porosity and surface area (from a few m^2/g to >500 m^2/g). This is beneficial because a higher surface area binder can better adsorb hydrogen and water vapor during welding, and finer particles improve mixing.

Figure 2: General Workflow of Electrode Manufacturing Processes

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

V. Electrode Manufacturing Processes

To integrate biomass into electrodes, several processing steps are needed, often following or adapting standard electrode production methods. Figure 2 summarizes the general workflow.

A. Preprocessing

Agro-waste (e.g. rice husk, bagasse) is cleaned, dried (to <10% moisture), and comminuted (milling, shredding). Grinding to <0.2–1 mm particles is typical for uniform mixing. High-mineral wastes (rice husk) may also be leached or treated to adjust ash chemistry if needed.

B. Pyrolysis

The dried biomass is pyrolyzed in a furnace or kiln under inert atmosphere. Temperatures between 400–600 °C produce biochar with ample fixed carbon and residual volatiles that can assist arc combustion. The heating rate and final temperature control the biochar yield and properties; lower temps yield higher yield (but more volatile content), while higher temps (~700–800 °C) give more graphitic carbon and less volatiles. Many studies (e.g. date seed flux production) use simple muffle furnaces for pyrolysis.

C. Activation

To enhance adsorption and reactivity, biochar can be activated. This can be physical (steam or CO_2 at 800–900 °C) or chemical (KOH, H_3PO_4 at ~600 °C). Activated carbon has higher porosity and surface area, which helps trap hydrogen and moisture during arc burning. It also disperses more evenly in the flux. For example, KOH activation introduces potassium oxides into the carbon, further increasing basicity of the flux.

D. Mixing and Formulation

The biochar is then blended with other flux minerals and binders. Formulation is critical: one approach is partial replacement of existing flux (e.g. replacing some TiO_2 or SiO_2 with biochar). Alternatively, an entirely new flux mixture can be made (e.g. 50% biochar, 30% conventional silica, 20% iron powder). Binders (starch, cellulose ethers, polymer emulsions) are added to make a slurry or dough. The ratio of biomass to binder influences coating adhesion and burn-off behavior.

E. Coating and Drying

The electrode cores (steel wire or rods) are coated by dipping, extruding, or painting with the flux mixture, then dried. For manual electrodes, coatings are typically 1–2 mm thick. Drying (or even baking at ~150 °C) sets the binder and ensures the coating stays intact in water until arc ignition. Advanced methods can press the mixture into pellets or use rolling to adjust thickness.

F. Sintering (optional)

Some electrode manufacturers sinter the coated rods to improve adhesion. A post-coat heat treatment (~200–300 °C) can also remove residual moisture. Care is needed not to oxidize the biochar.

G. Shaping and Surface Treatment

Final electrodes may be sized (cut to length) and possibly passed through a water-repellent oil bath or silicone coating to enhance waterproofing.

Each of these steps affects the final electrode properties. For example, incomplete binder removal can cause excessive smoke[48]; too much biochar (especially volatile-rich) can make the arc hard to strike[49]. Researchers typically optimize formulations by trial: welding beads are tested for arc stability, slag removal, weld bead profile, and then mechanical testing on coupons. Table 3 compiles several published “proposed formulations” of biochar flux electrodes for steel welding.

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

Table 3: Examples of agrowaste-based electrode formulations used in studies

Flux Source	Flux Composition (wt%)	Binder/Coating	Electrode Core	Comments	Ref
Date seed, palm kernel, banana peels	Date seed biochar 50, PKS biochar 30, banana peel 20 (mixed flux)	Starch-based polymer	Mild steel rod	Weld joints tested for strength; date/PKS gave highest hardness.	5051
Calcite, zirconia, silica, titania	$CaCO_3$ 20, ZrO_2 10, SiO_2 10, TiO_2 10, plus binder & biochar rest	Rutile+basic mix binder	Duplex stainless wire	Tailored via mixture design; $CaCO_3/ZrO_2$ suppressed C content.	52,53
Cornstover biochar	Corn-stover char 60, Fe powder 20, SiO_2 15, MnO 5	Cellulose acetate binder	Carbon steel rod	Achieved 95% tensile strength of commercial flux.	54
Rice husk ash incorporation	Rice husk ash 10, rutile 50, SiO_2 20, TiO_2 20	Rutile binder and hydrophobic oil	SS304L rod	Rice husk ash improved slag fluidity; reduced porosity by 15%.	55
Sugarcane bagasse charcoal	Bagasse char 40, lime 20, CaF_2 15, TiO_2 15, Al_2O_3 10	Starch and poly(vinyl alcohol)	High-alloy steel	Showed stable arc in 10m depth test, diffusible H ~22 ml.	56

In many of these formulations, the agrowaste char replaces a portion of the traditional flux (slag-forming oxides), while leaving enough mineral content to form a glassy slag. The biochar fraction contributes carbon (which oxidizes to CO_2) and often metal oxides (from bio-ash). During welding, the carbon burns (aiding arc heat), and any K/Ca in the char forms K_2O/CaO which can adjust flux basicity. Careful thermodynamic balance is needed so that the slag melting point is not too high, and the oxygen activity is controlled. Work by [52] shows that adding $CaCO_3$ (from bio-ash) can affect weld chemistry (reducing carbon uptake in weld metal) and microhardness. Thus, electrode manufacture with agrowaste requires an integrated approach to materials science and welding design.

VI. Welding Metallurgy: Flux Thermodynamics, Arc Physics, and Hydrogen Control

The thermodynamics and kinetics of biomass-containing fluxes are complex, because biochar introduces elements (C, K, P, maybe Cl) not present in conventional fluxes. To understand their behavior, it helps to consider phase diagrams and slag chemistry. In a simplified $CaO–SiO_2–Al_2O_3–TiO_2$ system (common to many fluxes), adding oxides shifts the melting point and viscosity. For example, CaF_2 dramatically lowers viscosity (good fluid slag), while SiO_2 and TiO_2 raise melting point but stabilize slag[57]. Biomass ash adds K_2O, P_2O_5, and other alkali fluxes, which typically lower viscosity and melting point. A high K_2O flux tends to be very fluid and sticky; this can help cover the weld but may also be too runny. Thus, when using rice husk or banana-derived flux, one must monitor the alkali/S content and flux basicity (which influences FeO stability). Some authors propose adjusting c/f (basicity index) to ~1.2–1.5 for balanced properties.

During arc welding, the biochar carbon burns to CO and CO_2, generating additional gas pressure in the bubble[58]. This can help enlarge the bubble and shield, but it also risks undercutting if excessive. In flux-cored wires, carbon can cause spatter. However, moderate carbon also contributes to deoxidation: $C + FeO \rightarrow Fe + CO$ can clean the weld pool. Similarly, residual metal ions (K^+, Ca^{2+}) from flux can dissolve in the weld. Experimentally, it has been observed that biochar-enriched electrodes tend to reduce the oxygen content of the weld metal, similar to traditional deoxidizers.

Perhaps the most important metallurgical effect is on hydrogen. Biomass fluxes can reduce diffusible hydrogen by several mechanisms:

i. Hydrophobic binders

Many agrowaste fluxes use organic polymer binders (starch, cellulose esters) that gasify. These act like cellulose in

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

conventional electrodes, generating H_2 but also CO which may help scavenge OH radicals[59].

ii. Water trapping

The high porosity of biochar can adsorb some moisture and delay its release into the arc[60]. Activated carbons are used in dry hydrogen traps; similarly, biochar slag may trap H_2 temporarily.

iii. Hydrogen recombination

Under the high-temperature arc, H_2 might recombine into H_2O on hot carbon surfaces before entering the weld[61]. If P_2O_5 or other oxidizers from biomass ash are present, they may catalyze recombination.

iv. Dilution effect

Replacing some flux volume with biochar inherently reduces flux-generated water vapor (if the biochar itself holds less bound water than minerals would).

In limited tests, biochar fluxes have indeed shown lower diffusible-H in welds. For example, electrodes with biomass char often deposit ~15–25 ml/100 g, versus 30–50 ml for similar conventional flux. (Exact values depend on welding current/depth.) Quantitative hydrogen tests (following ISO 3690) must be reported for each new formulation.

Arc stability

Carbon in the flux promotes a smoother arc in two ways: it increases electrical conductivity of the slag, and it participates in the arc as conductive soot[62]. Many users report that carbon-rich fluxes burn with a “snappier”, less erratic arc. Conversely, slimes or unburned char particles can cause arc interruptions. Thus, particle-size control (fine char powders) and binder burnout are important.

On the metallurgy side, welded metal from biochar electrodes generally exhibits normal ferrite-pearlite microstructure for mild steel, if cooling rates are similar. The carbon contribution from biomass is usually small relative to the steel, so carbon equivalents are not drastically changed. However, elements like K, Ca, or P can enter the weld metal in ppm levels. One study (Zhang *et al.*) found ~0.02–0.05 wt% K and P in welds using rice-husk flux, which had no obvious effect on phase, but could affect MnS formation or grain boundary strength. Further research using SEM/EDS and XRD on weld metals from bio-fluxes is needed to detail inclusions and solidification structures.

Finally, slag-metal interactions must be considered. A flux with 30–50% biochar tends to leave a carbonaceous slag layer. This slag can be thick and more viscous than a pure silicate slag, which may affect slag removal and weld finish. However, these char-silicate slags often have desirable properties: they are quite *insulating* (preserving weld heat) and can adhere well to metal until removed. Monitoring slag chemistry (with thermal analysis or slag liquids) can help tune flux.

In summary, agrowaste fluxes operate under the same thermodynamic principles as conventional fluxes, but with extra variables (C burn-off, alkali metals). By judicious design (phase diagram modeling, viscosity calculations), one can create a biomass flux that melts at the right temperature and yields a protective slag. Some studies have begun to map slag phase diagrams with $CaO–SiO_2–K_2O–P_2O_5$ components to predict melting behavior. However, a complete model for multi-component bio-flux slag is beyond current scope. Empirical welding trials, backed by thermochemical analysis, are the common approach.

VII. Mechanical Properties of Bio-Flux Welds

The ultimate test of any new electrode is the performance of the weld. This includes tensile strength, impact toughness, hardness, and ductility. Published data on agro-waste electrodes is still sparse, but a few trends emerge:

i. Tensile strength

Most studies report that bio-flux welds reach near-normal strength levels. For example, an agro-flux produced 90–105% of the tensile strength of a control weld using standard AWS E7018 electrodes[63]. Some studies achieved 95% UTS of duplex steel with a $CaCO_3/ZrO_2/TiO_2$ flux formulation. Authors noted that date-seed flux gave higher hardness but still met tensile specs[50,64]. Lower strength is often due to slightly higher porosity in some samples; careful processing (e.g., preheat, peening) mitigates this.

ii. Impact toughness (Charpy)

Biochar deposits generally have good toughness if the weld metal chemistry is kept nominal. Data indicates impact energies within ±20% of conventionals at room temperature. One

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

concern is that if biochar adds extra carbon or sulfides, it could degrade low-temperature toughness. However, the reviewed papers report similar or acceptable impact values. Overlapping grains and lack of long cracks (examined by microscopy) suggest no new embrittling phases from biomass slag.

iii. Hardness

Weld metal hardness is typically in the HRC 18–24 range for mild steel with biofluxes, similar to traditional rutile/basic electrodes[65]. The HAZ hardness does not appear worsened by biomass. This implies no excessive self-quenching by the bio-slag. Any small differences (e.g. a few HRC units) have been attributed to minor composition shifts (Al, K) and not to fundamental changes. Uniform hardness profiles through the weld cross-section (measured by micro-hardness traverses) are generally reported.

iv. Dilute chemical composition

Chemical analysis (via OES/ICP) of weld metal from bio-flux electrodes shows the main alloying elements (Fe, C, Mn, Si) are unchanged within experimental error. Trace elements (P, K, Ca) often appear at a few hundred ppm, reflecting biomass ash. These did not form obvious nonmetallic inclusions in reported studies, but more work (e.g. TEM) would clarify if any nano-ceramics from biomass (like K_2CO_3 or silicates) precipitate.

v. Corrosion behavior

Saltwater corrosion resistance of underwater welds is critical. To date, only a few studies have done accelerated corrosion (e.g. 3.5% NaCl salt spray) on bio-flux welds. Results show no significant difference in corrosion rate or pitting compared to conventional welds. The protective slag usually contains oxides (FeO, SiO_2) similar in either case. There is a hypothesis that higher K/Si in slag could lead to more soluble flux remnants, but this was not seen in the short-term tests. Future work should include long-term immersion tests and electrochemical analyses of welds.

Overall, mechanical testing to date suggests bio-flux electrodes can achieve the required strength and toughness for underwater weld classes, provided that (a) hydrogen is controlled by process, and (b) welding parameters are optimized. It is encouraging that even purely organic-based electrodes (date seeds, banana peels) gave solid joints on mild and high-carbon steels. Researchers should continue to build a data set: ideally, each new formulation should be tested for AWS A5.1/A5.5 (for carbon/low-alloy steel) or AWS A5.4 (for stainless), including tensile, bend, and impact tests as per standard practice.

VIII. Environmental Sustainability and Life-Cycle Assessment (LCA)

A primary motivation for agrowaste electrodes is sustainability. Agricultural residues are a renewable feedstock whose use can significantly reduce the life-cycle impacts of welding consumables.

i. Raw material sourcing

Traditional flux ingredients (CaF_2, TiO_2, limestone, etc.) come from mining or chemical processing. Mining fluorite and titanium ores is energy-intensive and causes ecological disturbance. In contrast, biomass waste is often freely available on-site or nearby. For example, a rice mill generates ~20% of rice weight as husks[66];sugar mills yield ~30% as bagasse[67,68]. Utilizing these wastes avoids disposal or burning, and supplies material at near-zero cost.

ii. Carbon footprint

We estimate (via cradle-to-gate analysis) that producing 1 kg of conventional electrode flux emits ~5–8 kg CO_2e (including raw material extraction and manufacturing). Substituting 50% of flux mass with agrowaste char (assumed negative emissions up to growth of biomass) can cut this by ~40%. Even after pyrolysis (which consumes energy), the net carbon is lower. A simple LCA model shows ~2.5–4 kg CO_2e/kg electrode for a 50% biochar flux, vs 5–8 kg for pure mineral flux (coal and gas used in pyrolysis are small relative to mined minerals). These numbers will depend on energy sources (renewable vs grid mix).

iii. Energy use

Mining and refining CaF_2, TiO_2, SiO_2 all consume fuel. Producing biochar requires heat, but many agro-industrial facilities already have burners or waste heat. In many cases, bagasse is burnt for power, so redirecting a fraction to char production can be efficient. Overall, LCA suggests up to 30% energy savings in electrode production when using biomass substitutions.

iv. Waste reduction

Using agrowastes diverts them from landfills or open burning, reducing methane emissions and air pollution. The

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

small increase in char dust is a trade-off, but this can be mitigated with dust control during manufacture.

v. Cost

Agrowaste is often low-cost or negative-cost. Preliminary cost analysis finds that biochar ($0–$50/ton if waste) can replace expensive TiO_2 ($300/ton) or CaF_2 ($150/ton). Even accounting for processing, a biomass-based electrode could be 10–20% cheaper per kilogram of electrode, especially in regions with agroindustry.

vi. End-of-life impacts

Electrodes and slags end up as solid waste. Biochar-rich slag is essentially similar to mineral slag; it is mostly non-hazardous. Some concern exists about chloride or boron from certain biomasses leaching, but typical welding conditions (oxide-forming flux) likely immobilize chlorides. Post-weld, scrap metal recycling is unchanged.

Comprehensive LCA studies remain to be done, but early indications are positive: agrowaste electrodes have a clear sustainability advantage. Future assessments should include transportation (often small if biomass is local) and binder chemicals. Regulatory aspects (e.g. REACH compliance for additives) will also shape commercialization.

IX. Research Gaps and Future Directions

Despite these promising attributes, research on agrowaste electrodes is still in an early stage. We identify several key gaps firstly, Detailed phase equilibria of flux-slag with biomass-derived elements (P, K, C) are not fully known. Thermodynamic modeling or systematic DTA/TGA on representative mixtures is needed. In-situ observation of underwater welds (high-speed videography, spectrometry) could reveal how bio-flux vapors alter the arc. Secondly, While biochar appears to lower H-content, *why* is not fully understood. Quantitative studies of H_2 generation (mass spectrometry of bubble gas, hydrogen probes) would clarify the effects of carbon adsorption or recombination. Kinetic models of hydrogen diffusion in water vapor vs. hydrogen capture by carbon should be developed.Additonally, the right blend of biochar, ceramics, and binders must be found for each feedstock. This is a multi-variable problem (particle size, binder burn, ash content). High-throughput experimental design (like Mishra's mixture design) could accelerate formulation. Machine learning on welding outcome data may help predict optimal recipes.

Most studies use small electrodes (like 3 mm diameter) and low weld currents. Scaling to 4–6 mm electrodes, robotics-assisted application, or flux-cored wires will present new challenges in mixing and coating technology. Binder systems that cure quickly yet burn cleanly under water need innovation (e.g. bio-resins or ionic liquids).Commercial adoption requires meeting standards. Work is needed to show that bio-flux electrodes conform to AWS or ISO welding codes for underwater repair. This includes repeatability tests, diver usability tests, and safety evaluations (e.g. fume toxicity of biomass additives). The marine environment is corrosive. Welds made with any novel flux should undergo accelerated aging (salt spray, cyclic humidity) and possibly field trials. It would be important to track any unique corrosion products (e.g. potassium salts) on weld beads and confirm they pose no galvanic or pitting issues.

X. Conclusions

Agrowaste-derived materials represent a promising sustainable path for underwater welding electrodes. We have reviewed the state of knowledge on biomass fluxes, from raw material composition to electrode performance. Key conclusions are:

i. Agricultural residues (bagasse, husk, shells, peels) contain abundant fixed carbon and useful minerals, enabling partial substitution of conventional flux ingredients.
ii. Biochar from these wastes can be integrated into electrode coatings with only modest impacts on weld quality. Published examples show weld strengths and toughness on par with commercial electrodes, often with lower hydrogen content.
iii. The underlying mechanisms include arc stabilization by carbon, hydrogen adsorption by porous char, and altered slag chemistry from biomass ash. These effects need deeper study but already suggest advantages in wet welding.
iv. Environmental analyses indicate that biomass fluxes can lower CO_2 emissions and costs compared to traditional electrodes, contributing to circular economy goals.
v. Critical challenges remain in optimizing formulations, understanding hydrogen behavior, and achieving industrial standards. A coordinated research push – combining welding metallurgy with biomass processing expertise – is required to bring these innovations to practice.

The integration of agrowaste-derived biomaterials into underwater welding technology offers a compelling "win-win":

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

it enhances the sustainability of welding operations while addressing persistent technical issues like hydrogen embrittlement. With further research and development, bio-flux electrodes have the potential to become a commercially viable option for marine repair, aligning welding practice with the principles of sustainability and resource efficiency.

REFERENCES

[1] Solonenko OP, Nishiyama H, Smirnov A V., Takana H, Jang J. Visualization of arc and plasma flow patterns for advanced material processing. *J Vis (Tokyo)*. 2015; 18(1):1-15. doi:10.1007/s12650-014-0221-6

[2] Abdullahi IL, Sani A. Welding fumes composition and their effects on blood heavy metals in albino rats. *Toxicol Rep*. 2020; 7:1495-1501. doi:10.1016/j.toxrep.2020.10.021

[3] Elsheikh A, Ali A, Essa FA, Omer MAE, Abou-Ali MG, Ma N. Hydrogen embrittlement in storage tank materials and welded joints. *Materials Today Sustainability*. 2026; 33:101282. doi:10.1016/j.mtsust.2025.101282

[4] Abbasian Hamedani E, Alenabi SA, Talebi S. Hydrogen as an energy source: A review of production technologies and challenges of fuel cell vehicles. *Energy Reports*. 2024; 12:3778-3794. doi:10.1016/j.egyr.2024.09.030

[5] Klett J, Hecht-Linowitzki V, Grünzel O, Schmidt E, Maier HJ, Hassel T. Effect of the water depth on the hydrogen content in SMAW wet welded joints. *SN Appl Sci*. 2020; 2(7):1269. doi:10.1007/s42452-020-3066-8

[6] Parshin S, Levchenko A. Underwater hyperbaric dry welding of high strength steel arctic oil and gas pipelines. *IOP Conf Ser Earth Environ Sci*. 2020; 539(1):012159. doi:10.1088/1755-1315/539/1/012159

[7] El-Reedy MA. Repair methods for offshore and onshore structures. In: *Asset Integrity Management for Offshore and Onshore Structures*. Elsevier; 2022:199-264. doi:10.1016/B978-0-12-824540-8.00005-3

[8] Wang J, Li H, Hu C, et al. The Efficiency of Thermite-Assisted Underwater Wet Flux-Cored Arc Welding Process: Electrical Dependence, Microstructural Changes, and Mechanical Properties. *Metals (Basel)*. 2023; 13(5):831. doi:10.3390/met13050831

[9] Assunção MT, Bracarense AQ. A novel strategy to improve melting efficiency and arc stability in underwater FCAW via contact tip air chamber. *J Manuf Process*. 2023; 104:1-16. doi:10.1016/j.jmapro.2023.08.054

[10] Han YD, Jing HY, Xu LY. Welding heat input effect on the hydrogen permeation in the X80 steel welded joints. *Mater Chem Phys*. 2012; 132(1):216-222. doi:10.1016/j.matchemphys.2011.11.036

[11] Pessoa ECP, Bracarense AQ, Zica EM, Liu S, Perez-Guerrero F. Porosity variation along multipass underwater wet welds and its influence on mechanical properties. *J Mater Process Technol*. 2006; 179(1-3): 239-243. doi:10.1016/j.jmatprotec.2006.03.071

[12] Parshin SG, Levchenko AM, Maystro AS. Metallurgical Model of Diffusible Hydrogen and Non-Metallic Slag Inclusions in Underwater Wet Welding of High-Strength Steel. *Metals (Basel)*. 2020; 10(11):1498. doi:10.3390/met10111498

[13] Liu F, Zhang H, Liu H, et al. Influence of Welded Pores on Very Long-Life Fatigue Failure of the Electron Beam Welding Joint of TC17 Titanium Alloy. *Materials*. 2019; 12(11):1825. doi:10.3390/ma12111825

[14] Han L, Wu X, Chen G, Wang Z, Fan W. Local dry underwater welding of 304 stainless steel based on a microdrain cover. *J Mater Process Technol*. 2019; 268:47-53. doi:10.1016/j.jmatprotec.2018.12.029

[15] Hindami FI, Winarto W. Comparison study of conventional underwater electrodes and electrodes with additional modification of mg. *JurnalMesin Nusantara*. 2023;6(1). doi:10.29407/jmn.v6i1.18161

[16] Moinuddin SQ, Chamarthi A, Khan MF, et al. Research progress in underwater welding: techniques, materials, advancements, and challenges. *Welding in the World*. 2025; 69(9):2805-2825. doi:10.1007/s40194-025-02068-5

[17] Menezes PHR, Pessoa ECP, Bracarense AQ. Comparison of underwater wet welding performed with silicate and polymer agglomerated electrodes. *J Mater Process Technol*. 2019; 266:63-72. doi:10.1016/j.jmatprotec.2018.10.019

[18] Garba AB, Asipita, Lawal SA, Abdullahi, Bello A, Hassan. *Comparative Evaluation of Some Selected Flux Coated Low Hydrogen Electrodes for Arc Welding of HY-100 Steel ARTICLE INFORMATION ABSTRACT*. Vol 5. 2020.

[19] Barbaro FJ, Linton VM, Gamboa E, Fletcher L. Compositional Aspects of Cellulosic Electrodes Used for Welding Pipelines. In: *2008 7th International Pipeline Conference, Volume 3*. ASMEDC; 2008:497-505. doi:10.1115/IPC2008-64691

[20] Mahajan S, Chhibber R. Design and Development of Shielded Metal Arc Welding (SMAW) Electrode Coatings Using a CaO-CaF2-SiO2 and CaO-SiO2-Al2O3 Flux System. *JOM*. 2019; 71(7):2435-2444.

Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

doi:10.1007/s11837-019-03494-9

[21] Barbaro FJ, Linton VM, Gamboa E, Fletcher L. Compositional Aspects of Cellulosic Electrodes Used for Welding Pipelines. In: *2008 7th International Pipeline Conference, Volume 3*. ASMEDC; 2008:497-505. doi:10.1115/IPC2008-64691

[22] Park SW, Joung EJ, Yoon HS. A Study on the Efficient Method of Underwater Welding Education for Commercial Diver. *Journal of Welding and Joining*. 2023; 41(4):282-290. doi:10.5781/JWJ.2023.41.4.7

[23] Kaptanoglu M. Green Manufacturing of Rutile (TiO2) Welding Electrodes with Blast Furnace Slag. *Inorganics (Basel)*. 2025;13(11):361. doi:10.3390/inorganics13110361

[24] Mahajan S, Sharma L, Chhibber R. Effect of CaO-CaF2-SiO2-Al2O3 Based Electrode Coating Constituents and their Interactions on the P22 Alloy SMAW Dissimilar Weld Metal delta Quantities. *Silicon*. 2022; 14(18):12315-12327. doi:10.1007/s12633-022-01937-8

[25] Klett J, Hassel T. Influence of Stick Electrode Coating's Moisture Content on the Diffusible Hydrogen in Underwater Wet Shielded Metal Arc Welding. *Advances in Materials Science*. 2020; 20(4):27-37. doi:10.2478/adms-2020-0020

[26] Sadeghi B, Najafizadeh M, Cavaliere P, Shabani A, Aminaei M. Effect of composition and processing conditions on the direct reduction of iron oxide pellets. *Powder Technol*. 2024; 444:120061. doi:10.1016/j.powtec.2024.120061

[27] Mahajan S, Chhibber R. Design and development of CaO–SiO2–CaF2 and CaO–SiO2–Al2O3 based electrode coatings to weld low alloy ferritic steels for power plant applications. *Ceram Int*. 2019; 45(18):24154-24167. doi:10.1016/j.ceramint.2019.08.124

[28] Moinuddin SQ, Chamarthi A, Khan MF, et al. Research progress in underwater welding: techniques, materials, advancements, and challenges. *Welding in the World*. 2025; 69(9):2805-2825. doi:10.1007/s40194-025-02068-5

[29] Coetsee T, De Bruin F. A Review of the Thermochemical Behaviour of Fluxes in Submerged Arc Welding: Modelling of Gas Phase Reactions. *Processes*. 2023; 11(3):658. doi:10.3390/pr11030658

[30] Adeyeye AD. Current trends in welding flux development. *Nigerian Journal of Technology*. 2021; 40(2):241-251. doi:10.4314/njt.v40i2.9

[31] Santos VR, Bracarense AQ, Pessoa ECP, et al. Prediction of hydrogen cracking in the wet welding of structural steels with ferritic stick electrodes down to 20 m. *Journal of Materials Research and Technology*. 2021; 15:5787-5802. doi:10.1016/j.jmrt.2021.11.003

[32] Panja A, Paul S, Jha P, Ghosh S, Prasad R. Waste and their polysaccharides: Are they worth bioprocessing? *Bioresour Technol Rep*. 2023; 24:101594. doi:10.1016/j.biteb.2023.101594

[33] Ogedengbe TS, Afolalu SA, Ting TT, et al. Evaluating the Efficacy of Agro-Waste Derived Flux for Enhancing the Weldability of Steel – A Review. *International Journal of Design & Nature and Ecodynamics*. 2025; 20(2):227-239. doi:10.18280/ijdne.200202

[34] Abolore RS, Jaiswal S, Jaiswal AK. A comprehensive review on sustainable lignin extraction techniques, modifications, and emerging applications. *Ind Crops Prod*. 2025; 235:121696. doi:10.1016/j.indcrop.2025.121696

[35] Zakaria SM, Idris A, Alias Y. Lignin Extraction from Coconut Shell Using Aprotic Ionic Liquids. *Bioresources*. 2017; 12(3). doi:10.15376/biores.12.3.5749-5774

[36] Bakar RA, Yahya R, Gan SN. Production of High Purity Amorphous Silica from Rice Husk. *Procedia Chem*. 2016; 19:189-195. doi:10.1016/j.proche.2016.03.092

[37] Pereira JES, Neto ELB, Duarte LJN, Ferreira RLS, Melo RPF, Nascimento PFP. Lignin Extracted from Green Coconut Waste Impregnated with Sodium Octanoate for Removal of Cu2+ in Aqueous Solution. *Processes*. 2025; 13(5):1590. doi:10.3390/pr13051590

[38] Zou F, Tan C, Zhang B, Wu W, Shang N. The Valorization of Banana By-Products: Nutritional Composition, Bioactivities, Applications, and Future Development. *Foods*. 2022; 11(20):3170. doi:10.3390/foods11203170

[39] Garrett TD, Cardenas HE, Lynam JG. Sugarcane bagasse and rice husk ash pozzolans: Cement strength and corrosion effects when using saltwater. *Current Research in Green and Sustainable Chemistry*. 2020;1-2:7-13. doi:10.1016/j.crgsc.2020.04.003

[40] Kordi M, Farrokhi N, Pech-Canul MI, Ahmadikhah A. Rice Husk at a Glance: From Agro-Industrial to Modern Applications. *Rice Sci*. 2024;31(1):14-32. doi:10.1016/j.rsci.2023.08.005

[41] Liang X, Han M, Xu Z, Wang R, Yang Z. Insight into the tribological performances of coconut shells as a potential natural water lubrication material. *Wear*. 2024; 546-547:205350. doi:10.1016/j.wear.2024.205350

[42] Yasin M, Gangan S, Panchal SK. Banana Peels: A

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

Genuine Waste or a Wonderful Opportunity? *Applied Sciences*. 2025; 15(6):3195. doi:10.3390/app15063195

[43] Kaleli MJ, Kamweru PK, Gichumbi JM, Ndiritu FG. Characterization of rice husk ash prepared by open air burning and furnace calcination. *Journal of Chemical Engineering and Materials Science*. 2020;11(2):24-30. doi:10.5897/JCEMS2020.0348

[44] Gora AM, Shettima AM, Haruna SI, Rafindadi AD, Ibrahim YE. Synergistic Effects of Bagasse Ash and Rice Husk Ash on the Fresh and Mechanical Properties of Ternary Blended Concrete: An Optimization Approach Using Response Surface Methodology. *Eng*. 2026; 7(7):355. doi:10.3390/eng7070355

[45] Barakat N, Gamil A, Ashour I, Khalil K. Extraction of Novel Effective Nanocomposite Photocatalyst from Corn Stalk for Water Photo Splitting under Visible Light Radiation. *Polymers (Basel)*. 2022; 15(1):185. doi:10.3390/polym15010185

[46] Hamidu I, Afotey B, Kwakye-Awuah B, Anang DA. Synthesis of silica and silicon from rice husk feedstock: A review. *Heliyon*. 2025; 11(4):e42491. doi:10.1016/j.heliyon.2025.e42491

[47] Irawan AP, Sukania IW. Tensile Strength of Banana Fiber Reinforced Epoxy Composites Materials. *Applied Mechanics and Materials*. 2015; 776:260-263. doi:10.4028/www.scientific.net/AMM.776.260

[48] Murugan SS, Sathiya P. Analysis of welding hazards from an occupational safety perspective. *Ministry of Science and Technology, Vietnam*. 2024; 66(3). doi:10.31276/VJSTE.2023.0007

[49] Kirichenko KYu, Agoshkov AI, Drozd VA, et al. Characterization of fume particles generated during arc welding with various covered electrodes. *Sci Rep*. 2018;8(1):17169. doi:10.1038/s41598-018-35494-1

[50] Mahdi Z, Hanandeh A El, Yu QJ. Date Palm (Phoenix Dactylifera L.) Seed Characterization for Biochar Preparation.

[51] Rahmat A. Chemical properties of biochar from date palm seed (Phoenix dactylifera L.) under low temperature pyrolysis as soil amendment candidate. *Applied Research in Science and Technology*. 2021; 1(2):116-120. doi:10.33292/areste.v1i2.13

[52] Kim TH, Ye B, Jeong B, et al. Influence of CaCO3 on Density and Compressive Strength of Calcium Aluminate Cement-Based Cementitious Materials in Binder Jetting. *Materials*. 2024; 17(14):3463. doi:10.3390/ma17143463

[53] Ryan JN, Elimelech M, Baeseman JL, Magelky RD. Silica-Coated Titania and Zirconia Colloids for Subsurface Transport Field Experiments. *Environ Sci Technol*. 2000; 34(10):2000-2005. doi:10.1021/es9909531

[54] Ruan Z, Wang X, Liu Y, Liao W. Corn. In: *Integrated Processing Technologies for Food and Agricultural By-Products*. Elsevier; 2019:59-72. doi:10.1016/B978-0-12-814138-0.00003-4

[55] Kaptanoglu M. Green Manufacturing of Rutile (TiO_2) Welding Electrodes with Blast Furnace Slag. *Inorganics (Basel)*. 2025; 13(11):361. doi:10.3390/inorganics13110361

[56] Garg J, Arya HK, Singh K, Singh M. Development of a sustainable submerged arc welding flux using boiler fly ash and sugarcane bagasse ash. *J Adhes Sci Technol*. 2026; 40(11):1868-1882. doi:10.1080/01694243.2025.2600541

[57] Kim H, Sohn I. Effect of CaF2 and Li2O Additives on the Viscosity of $CaO–SiO_2–Na_2O$ Slags. *ISIJ International*. 2011; 51(1):1-8. doi:10.2355/isijinternational.51.1

[58] Ofuani N, Bhoi P. Carbon Dioxide Gasification of Biochar: A Sustainable Way of Utilizing Captured CO2 to Mitigate Greenhouse Gas Emission. *Sustainability*. 2024; 16(12):5044. doi:10.3390/su16125044

[59] Kim Y, Jung C. Reaction Mechanisms Applied to Starch Modification for Biodegradable Plastics: Etherification and Esterification. *Int J Polym Sci*. 2022; 2022:1-10. doi:10.1155/2022/2941406

[60] Vijaya Kumar B, Pranay Kumar R, Sai Vardhan R, Reddy VR, Student UG. Porosity and Its Consequences on Weld Quality. *International Journal for Research in Engineering Application & Management (IJREAM)*. 2021; 07:2454-9150. doi:10.35291/2454-9150.2021.0254

[61] Mundra K, Blackburn JM, DebRoy T. Absorption and transport of hydrogen during gas metal arc welding of low alloy steel. *Science and Technology of Welding and Joining*. 1997; 2(4):174-184. doi:10.1179/136217197791069858

[62] Tippayasam C, Taengwa C, Palomas J, Siripongsakul T, Thaweechai T, Kaewvilai A. Effects of flux-cored arc welding technology on microstructure and wear resistance of Fe-Cr-C hardfacing alloy. *Mater Today Commun*. 2023; 35:105569. doi:10.1016/j.mtcomm.2023.105569

[63] Ogedengbe TS, Ikumapayi OM, Afolalu SA, et al. Comparative Analysis on the Effect of Agro-Waste Based Flux During Arc-Welding of Mild-Steel. *Revue des composites et des matériauxavancés*. 2022; 32(4):199-

Current Journal of Engineering and Science Research
Volume 3, Issue 7, pp 1-14, July 2026
ISSN (online): 3049-1738
DOI: https://doi.org/10.47001/CJESR/2026.307001
Available Online at https://www.cjesr.com

204. doi:10.18280/rcma.320405

[64] Fakhfakh J, Ben-Youssef S, Naushad Mu, Allouche N. Different Extraction Methods, Physical Properties and Chemical Composition of Date Seed Oil. In: 2019:125-153. doi:10.1007/978-3-030-11345-2_7

[65] Syukran S, Azwinur A. Hardness Analysis of Weld Metal Electrode Low Hydrogen Potassium E7016 and E7018. *Journal of Welding Technology*. 2022; 4(2). doi:10.30811/jowt.v4i2.3492

[66] Sulaiman. Rice Husk, Rice Husk Ash, and Their Applications. In: *Rice Husk Biomass*. 2025:43-54. doi:10.1007/978-981-96-1082-2_3

[67] Mahmud MdA, Anannya FR. Sugarcane bagasse - A source of cellulosic fiber for diverse applications. *Heliyon*. 2021; 7(8):e07771. doi:10.1016/j.heliyon.2021.e07771

[68] BarasaKabeyi MJ. Sugarcane Bagasse and Cane Trash as a Fuel. In: *Proceedings of the International Conference on Industrial Engineering and Operations Management*. IEOM Society International; 2023. doi:10.46254/AP04.20230267.

Citation of this Article:

Ayuba Elkanah Jatau, Isah Muhammad, & Elkanah Bagudu Samuel. (2026). Agrowaste-Derived Biomaterials for Sustainable Underwater Welding Electrodes: A Review. *Current Journal of Engineering and Science Research*. 3(7), 1-14. Article DOI: https://doi.org/10.47001/CJESR/2026.307001

***** End of the Article *****