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Evaluating the Efficacy of Agro-Waste Derived Flux for Enhancing the Weldability of Steel – A Review

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ABSTRACT

Material failure often leads to disastrous consequences, but it can often be effectively prevented. The need to prevent material failure has sparked extensive research into strengthening engineered materials, leading to diverse approaches in material enhancement. Global population growth has intensified the demand for agricultural products, leading to increased environmental pollution and degradation over time. As a result, the use of these agricultural residues as flux materials has been explored in engineering applications. This study reviewed various techniques to enhance the structural integrity of carbon steels by incorporating agricultural waste products, notably date seeds, palm kernel shells, and banana peels. A comprehensive analysis was conducted on the engineering properties of these waste materials. The findings indicate that date seeds and palm kernel shells exhibit superior reinforcement capabilities, making them more effective in enhancing the performance of various steel types compared to banana peels. Consequently, it is advisable to consider the utilization of date seeds and palm kernel shells for engineering applications.

1. INTRODUCTION

Engineering materials play a crucial role in ensuring the performance and durability of machinery in various applications [1-3]. These materials are instrumental in meeting essential human needs, such as transportation, clothing, and modern technologies, including computers and mobile phones [4]. Various materials have been utilized in engineering applications, emphasizing the need for effective utilization of diverse engineering materials to create competitive and cost-efficient products for the global market [5]. Engineering materials can be broadly categorized into metals and non-metals. Non-metals are known for their poor heat and electrical conductivity, while metals exhibit excellent thermal and electrically conductive properties. Additionally, there are other engineering materials beyond these primary classifications, including polymers, ceramics, and alloys [6, 7]. Among metals, steel stands out as one of the most widely used [8]. Carbon steel, a type of steel with a carbon content ranging from 0.2% to 1.5%, can be further classified into three categories: low carbon, medium carbon, and high carbon steel [9, 10]. Carbon steel is highly significant due to its remarkable toughness, ductility, cost-effectiveness, and superior mechanical properties such as malleability in order to meet diverse engineering needs [11]. The manufacturing of different types of steel involves specific procedures, one of the key processes being welding. Welding is the process of joining two or more metals through the application of heat and pressure, regardless of whether they are similar or dissimilar. This technology has significantly contributed to the construction of various structures, including automobiles, railways, bridges, buildings, and more [12-16]. There are several welding methods available, such as Metal Inert Gas (MIG) welding, stick welding, Tungsten Inert Gas (TIG) welding (also known as Gas Tungsten Arc Welding or GTAW), gas welding, Metal Active Gas (MAG) welding, Flux Cored Arc Welding (FCAW), Submerged Arc Welding (SAW), Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), and others [17-21]. Arc welding is a specific welding process in which an electric arc between an electrode and the workpiece generates the heat needed to fuse the metals. During this process, a pool of molten metal forms near the tip of the electrode and solidifies as the electrode moves along the joint. The use of welding flux is essential in this method to enhance the weldability of the materials [22-25].

Welding flux, comprising a combination of carbonate and silicate materials, plays a crucial role in welding processes by shielding the weld from atmospheric gases. Its significance lies in preventing the base and filler materials from interacting with the surrounding environment, particularly air, which can lead to oxide formation [26].

Agricultural waste is typically rich in silicates and carbonates. Ongoing research aims to explore its sustainable utilization for flux production in welding applications. Therefore, this study reviews existing research in this field to evaluate the properties of flux derived from agricultural waste.

2. METHODOLOGY

This study employed the use of some scientific databases (Google Scholar, Web of Science, Scopus and ResearchGate) for sourcing relevant literatures for the review. The database search engines were queried for specific keywords such as agrowastes, banana peel, date seed, fluxes, palm kernel shell, welding technology, weldment, flux preparation, arc welding types, electrodes and mechanical properties of welded joints. The literature search was grouped into 2 to facilitate ease of acquisition of related materials. The first group focused on welding technology and flux usage for welding. The second group focused on the use of various agrowastes for welding fluxes. Emphasis here was put on some selected waste types such as banana peel, palm kernel shell, date seeds, sugarcane bagasse. All retrieved literatures (150 articles) were read and screened carefully using their titles, abstracts and conclusions to harvest the literatures (98 articles) relevant to the study. For the sake of recency of information retrieved for the review, material sourcing was limited to the last ten years except for cases where there was a need for older but vital information.

2.1 Welding technology

Many products cannot be created as a single unit; therefore, the construction of individual components is vital before they are brought together through assembly (joining) [27].

Joining technologies can be broadly classified into mechanical methods and liquid-solid-state processes. The processes employed to connect liquid and solid materials encompass welding techniques [28, 29].

Welding is a fabrication method that unites materials, typically metals or thermoplastics, by melting them at elevated temperatures and allowing them to cool, forming a solid and cohesive bond. In the process of welding, metals are joined by heating and fusing their edges, with or without the introduction of filler material, to create a robust, uniform connection [30-34]. For temporary connections, various methods are employed, including riveting, bolting, seaming, soldering, and brazing. Welding has its own distinct vocabulary, incorporating terms such as electrode, filler material, and welding rod [35].

The fundamental principle underlying welding is the generation of intense heat, which results in a pool of molten material. As this molten material cools, it forms a bond that can be even stronger than the parent metal. Pressure, either alone or in conjunction with heat, can also be utilized to create welds. To safeguard the melted and filled metals from contamination or oxidation, a shielding gas may be used [36].

Arc welding is considered one of the most cost-effective and efficient welding methods. The microstructure typically exhibits acicular ferrite and pearlite grains, and the primary objective is to enhance the microstructure, weld joints, impact strength, and weld integrity. In the assessment of low mechanical properties for carbon steel, methods like arc metal arc welding are employed to investigate the impact of temperature values [37-39].

Fusion welding without the application of pressure is a method used to join two dissimilar metals by melting and fusing their connecting edges, with or without the addition of filler material, and without the use of any form of pressure [40-42].

2.2 Development of flux

Welding flux plays a pivotal and diverse role in the welding process, influencing crucial aspects such as spatter control, deposition rate, arc stability, slag removal, penetration regulation, and weld-bead morphology. These functions profoundly impact the welding process's productivity, effectiveness, and the creation of high-quality weld deposits [43]. Moreover, welding flux safeguards the molten metal, influences the chemical composition of weld metal, dictates the mechanical properties of the weldment, shapes microstructural and other metallurgical attributes, and manages fume generation and potential toxicity.

Table 1 shows the results from studies on flux performance for conventional and agrowaste based flux. These studies shed light on the potential of innovative flux development to optimize welding processes and improve weld characteristics.

To delve deeper into recent advancements in welding flux development, this paper examines the formulation, characteristics, and applications of various flux systems. It analyzes the impact of different flux compositions on welding performance and weld quality, offering insights into the instrumental role of flux in welding optimization. Through a comprehensive review of recent research endeavors, this paper highlights the remarkable potential of innovative flux development and its importance in enhancing welding processes.

Table 1. Comparative studies in flux performance for conventional and agrowaste based flux

Study	Focus	Key Findings
Sharma et al. [36]	Submerged Arc Welding (SAW) flux systems	Developed new flux formulations (TiO_2-SiO_2-CaO and SiO_2-CaO-Al_2O_3) to optimize performance in SAW.
Afolalu et al. [37]	Coconut shell-based iron oxide flux	Demonstrated the viability of using agricultural waste to create high-quality flux powder for welding applications.
Dwidewi [38]	Exothermic flux for SAW	Established a positive correlation between the amount of thermit mixture added to the flux and the depth of weld penetration.
Afolalu et al. [42]	Eggshell-derived flux powder for MIG welding	Highlighted the effectiveness of using eggshell-based flux powder in MIG welding to improve weld strength and mitigate oxidation.

Table 2. Agrowaste types and properties

Agrowaste	Effects on Flux Development and Properties
Rice Straw	**Porosity:** Enhances soil porosity due to its fibrous structure, promoting water infiltration and root growth [2]. **Permeability:** Increases soil permeability by improving soil structure, allowing better movement of water and air [3]. **Organic Matter Content:** Adds organic matter to the soil upon decomposition, contributing to soil fertility and microbial activity [4]. **Nutrient Availability:** Releases nutrients such as nitrogen, phosphorus, and potassium as it decomposes, serving as a slow-release fertilizer [5].
Corn Stover	**Porosity:** Similar to rice straw, corn stover increases soil porosity, benefiting water retention and root penetration [6]. **Permeability:** Improves soil permeability by preventing compaction and enhancing soil aggregation [7]. **Organic Matter Content:** Adds carbon to the soil, improving soil structure and providing a food source for soil microbes. **Nutrient Availability:** Decomposes relatively slowly, releasing nutrients gradually over time.
Bagasse (Sugarcane Waste)	**Porosity:** Can improve soil aeration and water infiltration due to its fibrous nature. **Permeability:** Enhances soil permeability by preventing compaction and improving soil structure. **Organic Matter Content:** Adds organic carbon to the soil, enriching soil fertility and supporting microbial activity. **Nutrient Availability:** Contains moderate levels of nitrogen, phosphorus, and potassium, contributing to nutrient availability upon decomposition [11].
Wheat Straw	**Porosity:** Similar to other crop residues, wheat straw enhances soil porosity and water infiltration rates. **Permeability:** Helps maintain soil permeability by preventing soil compaction and improving soil structure [5]. **Organic Matter Content:** Adds organic carbon to the soil, enhancing soil fertility and supporting microbial life. **Nutrient Availability:** Decomposes relatively slowly, releasing nutrients gradually over time, contributing to long-term soil fertility [7].
Coffee Grounds	**Porosity:** Can improve soil porosity, promoting water infiltration and root growth [12]. **Permeability:** Enhances soil permeability by preventing compaction and improving soil structure. **Organic Matter Content:** Adds organic carbon to the soil, supporting microbial activity and soil health. **Nutrient Availability:** Contains nitrogen, phosphorus, potassium, and other micronutrients, providing immediate and slow-release nutrients upon decomposition [22].

2.2.1 Agro-waste

Agro-waste materials can exist in various forms, including liquids, slurries, or solid matter, with their specific composition being contingent on the agricultural processes and activities involved [44-46].

With the progression of civilization and improvements in living standards, there is a growing daily output of organic waste, encompassing items like household refuse, agricultural residues, and sludge [47-49]. This mounting generation of organic waste from industrial sources has presented a formidable challenge concerning the safe disposal of these materials [50]. Not only do these organic residues occupy significant space, but they also exert adverse impacts on the environment, constituting a substantial portion of the waste stream [51]. For instance, statistics from the FAO reveal that roughly 20 to 30 percent of fruits and vegetables end up as waste during both production and post-harvest handling. Within these organic leftovers from food processing facilities, there are components such as fruit seeds, citrus peels, pear peels, coconut shells, and eggshells [23]. Typically, these wastes find their way into landfills as a disposal method. However, this waste holds promise as a non-combustible resource for crafting environmentally sustainable packaging materials. This potential arises from the distinct cellulose composition, hemicelluloses, and proteins present in these materials, rendering them amenable to easy decomposition [8]. As a result, researchers are actively exploring alternative strategies for the decomposition or utilization of these agro-wastes in an environmentally sound manner. Table 2 displays various agrowastes sources and the effect they have when considered for flux development. A number of agrowastes materials have been analyzed over time as a viable substitute to be adopted for this purpose, popular among them are the date seed, palm kernel shell and banana peel.

(a) Date seed (Powder). Date seeds result from the process of extracting pits from dates, a procedure undertaken to produce pitted dates or date paste. In essence, these seeds are the residual elements of date palm (Phoenix dactylifera) fruits, featuring a small embryo encased in a typically oblong seed with grooves on its ventral side. The weight of date pits can range from 0.5g to 4g, constituting approximately 6 to 20% of the total fruit weight, contingent on factors such as ripeness, variety, and grade [52].

Date palms are renowned for thriving in warm climates and are extensively cultivated in regions like Egypt, the Canary Islands, Mexico, and various states in the United States, including California, Florida, and Arizona. Traditionally, date seeds have been discarded or repurposed as animal feed. Nevertheless, they hold potential utility as a source of oil, a coffee substitute, a raw material for producing activated carbon, or as an adsorbent for fluids containing dyes. The oil derived from date seeds possesses antioxidant properties that find application in cosmetics [53].

As can be seen in Tables 3 and 4, the physicochemical composition of date seeds encompasses moisture content ranging from 3.1% to 10.3%, protein content between 2.3% and 6.4%, fat content spanning 5.0% to 13.2%, ash content within the range of 0.9% to 1.8%, and carbohydrates constituting 71.9% to 87.0% [53]. The major mineral constituents of date seed are potassium, magnesium and sodium. These minerals are crucial for weldment strengthening, corrosion resistance and flux stabilization.

Table 3. Mineral constituent of date seed [54]

Mineral Constituent	mg/100g
Potassium	459.8/542.2
Sodium	21.7/26.1
Calcium	6.5/11.3
Magnesium	61.3/69.5
Iron	2.8/6.0
Manganese	1.3/1.7
Zinc	1.0/1.4
Copper	0.4/0.6

Table 4. Composition of date seed [55]

Varieties	Moisture%	Protein%	Fat%	Ash%	Carbohydrate%	Ref.
Mabseeli	3.1	3.9	5.0	1.0	87.0	Al-Farsi and Lee [56]
Um-sellah	4.4	5.4	5.9	1.2	83.1	Al-Farsi and Lee [56]
Shahal	5.2	2.3	5.1	0.9	86.5	Al-Farsi and Lee [56]
Fard	10.3	5.7	9.9	1.4	72.7	Hamada et al. [57]
Khalas	7.1	6.0	13.2	1.8	71.9	Hamada et al. [57]
Lulu	9.9	5.2	10.5	1.0	73.4	Hamada et al. [57]
Deglet noor	9.4	5.0	9.2	1.0	75.4	Besbes et al. [58]
Allig	8.6	4.7	11.6	1.0	74.1	Besbes et al. [58]
Ruzeiz	5.4	6.4	9.7	1.0	77.5	Sawaya et al. [59]
Sifri	4.5	5.9	10.0	1.1	78.5	Sawaya et al. [59]

(b) Palm kernel shell (Powder). The product of the oil palm tree (Elaeis guineensis) generates palm kernel shell as a waste byproduct during processing. These shells are particularly common in regions with warm climates, as the oil palm thrives in such conditions, making them about five times more prevalent in tropical areas due to the favorable climate. Palm kernel shells encapsulate the palm kernel and are surrounded by a fleshy fiber containing palm oil. Consequently, after the palm's fibrous fruit is processed to extract palm oil, palm kernel shells remain. However, the palm oil can be deliberately separated from the fleshy fiber to access the shell. To obtain the shell, it is cracked open procedure to reach the inner palm kernel nut [60].

Palm kernel shells find utility in various applications, including the manufacture of cutting tools, plastic polymer composites, cement and concrete production, reinforcement in concrete structures, and as a medium for energy generation [61]. Researchers have thoroughly examined the characteristics of palm kernel shells to assess their suitability for diverse applications (Table 5). Some of these notable traits include porosity, moisture content, lignin content, cellulose, solid density, and carbon content. One area that has recently garnered significant attention is the development of plastic composites using palm kernel shells [62]. Their cost-effectiveness and status as waste materials make palm kernel shells favorable filler for enhancing specific desired properties in various materials.

These shells, being a natural fiber, are abundant and easily accessible. They possess a low density and undergo rapid and complete biodegradation in the environment. Furthermore, palm kernel shells exhibit bulk chemical characteristics, with their composition containing carbon (46.75%), hydrogen (5.92%), oxygen (37.97%), nitrogen (0.68%), and sulfur (<0.08%) [63].

Table 5. Properties of oil palm kernel shell [64]

Property	Values
Micropore surface area(m^2g^{-1})	0.20
Apparent density (gcm^{-3})	1.47
Solid density (gcm^{-3})	1.53
BET Surface area (m^2g^{-1})	1.60
Porosity (%)	3.90
Lignin (%)	53.40
Cellulose (%)	29.70
Hemicellulose (%)	47.70
Ash (%)	1.10
Volatile (%)	0.10
Moisture (%)	7.96
Carbon (%)	18.70

(c) Banana peel (Ash). They are derived from the fruit of Musa paradisiaca commonly grown in tropical and subtropical regions, are a significant agricultural product with consistently increasing production. In the last two decades, banana production has risen from 70 million tonnes in 1999 to nearly 117 million tonnes in 2019 [65]. However, this surge in production also generates a substantial amount of waste in the form of discarded banana peels. These peels are often disposed of as part of household waste or at fruit markets, contributing to unpleasant odors due to the anaerobic digestion of biomass, which upsets the natural air balance. Even when ripe bananas are consumed, a considerable portion of bananas undergo industrial processing to produce products like banana flour, chips, and other processed foods, leading to a significant accumulation of banana peel waste. Traditionally, food industries and agriculture disposed of these peels in landfills. Hence, there is potential for the agricultural sector to benefit from transforming banana peels into a valuable resource [66-69].

Table 6. Composition of banana peel

Element Concentration	(mg/g)
Potassium	78.10 + 6.58
Calcium	19.20 + 0.00
Sodium	24.30 + 0.12
Iron	0.61 + 0.22
Manganese	76.20 + 0.00
Bromine	0.04 + 0.00
Rubidium	0.21 + 0.05
Strontium	0.03 + 0.01
Zirconium	0.02 + 0.00
Niobium	0.02 + 0.00
Moisture (%)	6.70 + 02.22
Ash (%)	8.50 +1.52
Organic matter (%)	91.50 + 0.05
Protein (%)	0.90 + 0.25
Crude Lipid (%)	1.70 + 0.10
Carbohydrate (%)	59.00 + 1.36
Crude Fibre (%)	31.70 + 0.25
Hydrogen cyanide (mg/g)	1.33 + 0.10
Oxalate (mg/g)	0.51 + 0.14
Phytate (mg/g)	0.28 + 0.06
Saponins (mg/g)	24.00 + 0.27

Chemical analysis reveals that banana peels are rich in potassium (7.8mg/g), accounting for 9.39% of their dry weight. They also contain notable amounts of magnesium, calcium, sodium, phosphorus, and various microelements such as iron, manganese, zinc, and copper (Table 6). Additionally, these peels possess substantial levels of total phenolic, flavonoid, and tannin compounds, with the methanolic extract exhibiting the highest concentration. This extract has demonstrated potent antioxidant and antibacterial properties against a range of microorganisms at a concentration of 600ppm, including both gram-positive and gram-negative bacteria, fungi, and yeast [70-74]. Therefore, exploring the value of banana peels, particularly in the form of ash, can have substantial implications for various applications, including agriculture and industry.

2.3 Biomass materials composition and review on fabrication method

2.3.1 Date seed flux preparation

The date seeds are subjected to a washing process to remove any impurities or contaminants. After washing, the seeds are soaked in Nitrous hydride, a chemical solution, possibly to facilitate certain reactions or to enhance the cleaning process. Following the soaking process, the seeds are flushed with clean water. This step likely aims to remove any residual chemicals or debris from the soaking process [75-77]. The date seeds are then boiled for 5-10 minutes at a temperature ranging between 80-90°C. Boiling could serve multiple purposes, such as further cleaning, softening, or activating certain components of the seeds. After boiling, the excess water is drained, and the date seeds are dried. This drying process is achieved by roasting the seeds in an oven for 6 hours at a temperature of 100°C. Roasting helps in removing moisture content, making the seeds suitable for further processing [78]. Once dried, the date seeds undergo smashing and grinding process. This mechanical process aims to break down the seeds into a finer form, possibly increasing the surface area for better integration into the flux [79].

The final step involves sieving the date seed powder. A manual 65 mesh sieve is used for this process. Sieving helps in achieving a uniform and fine powder by separating coarse particles. The mesh size (65) indicates the fineness of the powder. Figure 1 provides a visual representation of the date seed flux preparation process.

2.3.2 Palm kernel shell flux preparation

The first step involves grinding the palm kernel shells. Grinding is a mechanical process that aims to break down the shells into smaller, fine particles. This step enhances the overall consistency and properties of the flux material. After grinding, the material derived from the palm kernel shells is sieved. Sieving involves passing the ground material through a sieve to separate finer particles from coarser ones. The choice of sieve size determines the particle size distribution in the final flux material [72].

The simplicity of the process, which involve only grinding and sieving steps, suggests that PKS flux preparation is a more straightforward and less resource-intensive procedure compared to date seed flux preparation. Figure 2 presents a summary of the involved steps.

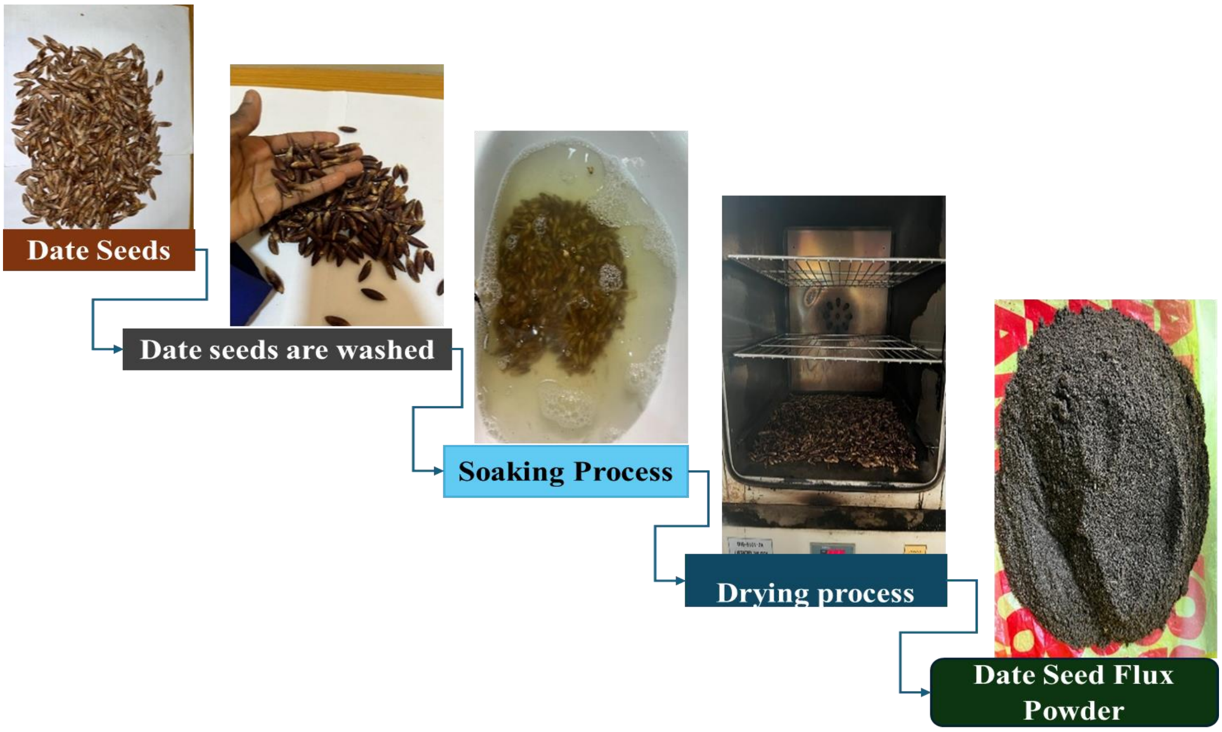

Figure 1. Date seed powder flux preparation [72]

2.3.3 Banana peel flux preparation

The preparation process for banana peel flux involves a series of steps to transform banana peels into a usable flux material. The banana peels are subjected to furnace for heating to facilitate proper drying. Heating helps remove moisture from the peels, making them more amenable to subsequent processing. Proper drying is crucial as it can affect the quality and characteristics of the final flux material. Once dried, the banana peels are broken into smaller pieces. Breaking the peels into smaller fragments likely aims to increase the surface area available for subsequent grinding. This step enhances the efficiency of the grinding process and contribute to the overall homogeneity of the flux material. The dried and broken banana peel pieces undergo a grinding process [80-84]. Grinding is a mechanical operation that reduces the size of the material into finer particles. This step is essential for achieving the desired particle size distribution and consistency in the flux material. The sequence of heating before breaking into smaller pieces indicates a deliberate order in the preparation process [85, 86]. Heating facilitates easier breaking of the peels into smaller fragments, preparing them for the subsequent grinding operation.

The use of banana peels as a flux material involves a combination of drying, breaking, and grinding steps as shown in Figure 3.

2.3.4 Measuring and cutting of steel samples

The high carbon steel rods were divided into 9 pieces measured at 47mm for each while the medium carbon steel rods were divided into 2 equal parts each with an equal length of 77.5mm. There was a total of 8 medium and high carbon steel rods each separated into four pairs for welding activity.

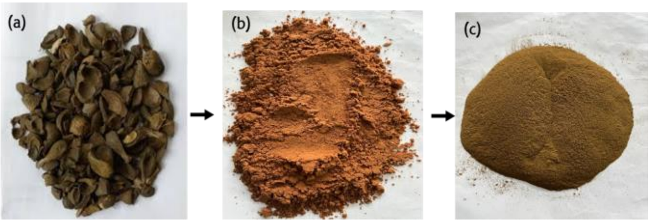

Figure 2. PKS flux preparation (a) PKS, (b) PKS after grinding, (c) PKS flux powder after sieving [73]

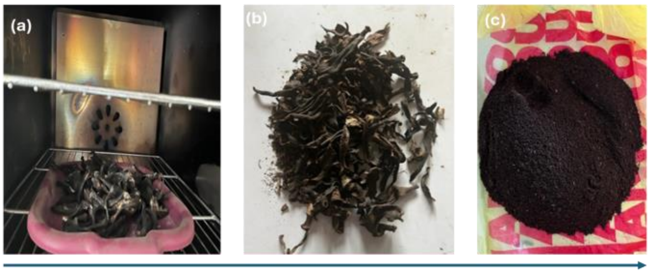

Figure 3. Processed banana peel (a) heating the banana peels, (b) heated banana peels, (c) Banana peel ash [75]

2.3.5 Welding of joints with arc welding

The welding process was carried out by arc. The electric arc welding machine was set to a temperature of 160℃ and the developed flux powders were applied on the joint edges of the high carbon steel and medium carbon steel rod samples while welding. Safety overall and eye safety goggles were worn to avoid operational hazard from splashing chips during welding operation.

2.4 Properties of fabricated fluxes

Tables 7 and 8 depict the outcomes of AAS analyses conducted on various processed materials, namely Date seed powder, Palm Kernel Shell, banana peels, and normal flux powder. Across all samples, significant levels of elements crucial for reinforcing welded sections were identified. For instance, Date seed powder exhibited notable proportions of Fe (21.25% weight volume), Calcium (23.76% volume), and Carbon (35.2% volume). Similarly, Palm Kernel Shell showed Fe at 0.3% weight volume, Calcium at 0.2% volume, and potassium at 0.1% volume. Additionally, banana peels demonstrated Fe at 0.97% weight volume, Calcium at 0.75% volume, and potassium at 0.24% volume. These elements, known for their ability to enhance metal strength, contribute significantly to reinforcing welded sections.

As seen in the abridged result (Table 8) for XRF analysis of High Carbon Steel sample, Iron (Fe), was the major constituent element found in all 4 welded joints samples. The elemental value occurred as follows; Normal flux – 97.224% (Fe), Date Seed Powder – 98.114% (Fe), Palm Kernel Shell – 96.231% (Fe) and Banana Peel Powder – 95.226% (Fe). Additionally, every flux sample except Banana peel powder presented elements with high strength and tensile properties such as Titanium (Ti). The result varied only slightly from that of Merchant [87], whose XRF analysis of Medium Carbon Steel sample (Table 9) showed trace presence of Mn apart from Cu, Zn, Co, Cr and Fe, which was also the major constituent.

Table 7. Element composition of different fabricated fluxes [76]

	Zn	Na	Mg	Fe	B	Cu	Ca	K	S	C	Si	O	Mn	Al	P	Ti
Date Seed Powder	5.12	3.15	4.65	21.25	0.02	0.56	23.76	6.23	0.01	35.25	-	-	-	-	-	-
Palm Kernel Shell	-	-	-	0.3	-	-	0.2	0.1	-	65.9	0.6	32.8	-	-	-	-
Banana peels	0.14	1.14	-	40	-	0.65	-	-	-	-	-	-	0.715	-	-	-
Normal flux Powder		0.2	19.7	0.6	0.002	0.003	29.0	1.7		-	18.6		9.8	14	0.815	5.57

Table 8. Flux element (HCS) [77]

	Value				
Flux Material	Fe	Co	Cr	Zn	Cu
Normal flux Powder	97.224	0.619	0.061	0.099	0.256
Date Seed	98.114	0.478	0.912	0.194	0.217
Palm Kernel Shell	96.231	0.613	0.064	0.098	0.429
Banana Peel Powder	95.226	0.667	0.036	0.073	0.212

Table 9. Flux element (MCS) [87]

	Value					
Flux Material	Fe	Co	Cr	Zn	Cu	Mn
Normal Flux Powder	98.168	0.513	0.045	0.067	0.113	0.456
Date Seed	97.254	0.376	0.876	0.064	0.147	0.638
Palm Kernel Shell	98.231	0.523	0.026	0.054	0.127	0.562
Banana Peel Powder	94.711	0.523	0.026	0.054	0.127	4.562

Table 10. Hardness test results for agrowaste based flux welded joints [40]

Parameter	Load at Maximum Tensile Stress	Maximum Tensile Stress (Mpa)	Maximum Tensile Strain (mm/mm)
100% Egg Shell	850.2565	81.234	0.0234
100% Coconut Shell	712.3254	75.234	0.0136
70% Egg Shell	847.4748	80.147	0.0213
30% Egg Shell	750.5489	79.321	0.0200
Normal Flux	785.2365	53.880	0.0102

The review encompassed an analysis of hardness characteristics across three distinct zones: base metal, welded joints, and heat-affected zones (Figure 4). Hardness values for Date Seed Powder-welded samples measured 122.23 BHN, 131.25 BHN, and 133.65 BHN, respectively. In contrast, Banana Peel-welded samples exhibited values of 85.91 BHN, 83.29 BHN, and 87.78 BHN, Palm Kernel Shell-welded samples showed 91.15 BHN, 94.53 BHN, and 95.63 BHN, and Normal Flux-welded samples recorded 90.58 BHN, 95.87 BHN, and 93.65 BHN (Figure 4).

These reviews demonstrate that Banana Peel Powder (BPP) welding offers enhanced resistance to degradation compared to Date Seed Powder, Palm Kernel Shell, and conventional electrode fluxes, attributed to higher hardness values correlating with increased tensile stress levels. This aligns with findings by Afolalu et al. [86] supporting the efficacy of novel flux materials in enhancing hardness over standard formulations.

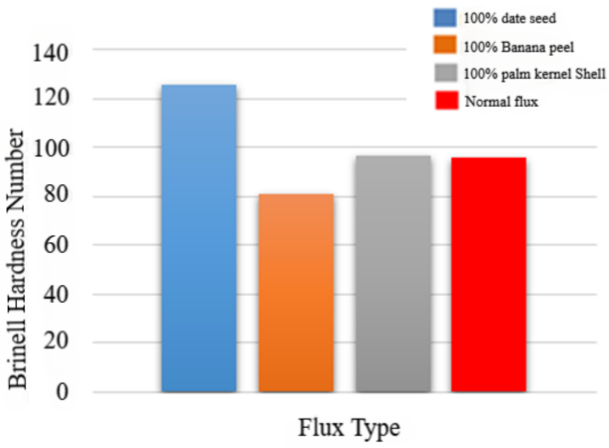

Figure 4. Hardness for welded joint for the 4 flux samples [86]

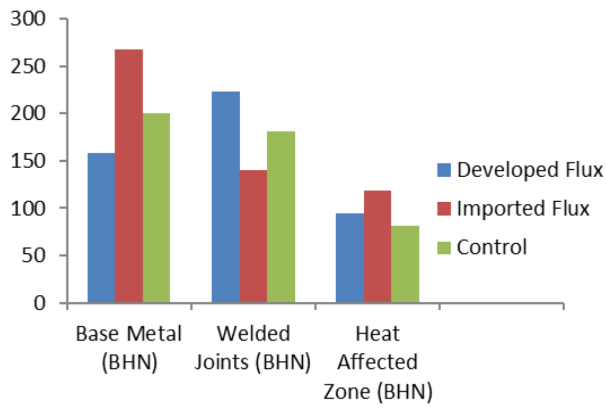

Figure 5. Brinell hardness for various parts of welded steel joints [40]

2.5 Mechanical properties analysis of welded steel joints

2.5.1 Hardness of welded joints

Steels are basically used in various engineering applications because they provide strength which is a core requirement in these areas of applications. It is therefore imperative that the welding of steels be done without compromising this very important aspect. The uses of various agrowastes to enhance the mechanical properties of various steel types have been previously studied. For example, Ihom et al. [88] experimented on the use of eggshell and sugarcane bagasse in strengthening welded joints of steels. The study results showed a record 51% improvement in hardness value of welded joints when the agro-waste based flux was used for welding steel compared with a normal flux usage. This revelation spurred a further study on the use of eggshell to strengthen various steel types by Verma and Taiwade [45]. The study centered on the improvement of the hardness of weldment of mild and galvanized steel types. They reported an improved hardness value of 222.74 HV and 100.93HV with the developed flux (enhanced with eggshell) which represented about 21% increase in hardness value obtained when compared with hardness values obtained when welding was done with normal flux. Obviously, the use of eggshell only by Afolalu et al. [12], though productive, yet could not replicate the same feat as Singh et al.'s [43] result. This signifies the part the fiber of the sugarcane bagasse could play in strengthening of welded joints of steels.

Afolalu et al. [7] carried out a comparative study on the influence of agrowastes based and custom fluxes on welded steel joints. As shown in Figure 5, the study result showed lots of promise for the developed flux as the hardness value of the welded region was highest for the developed flux. This interprets as an improvement in hardness value of welded joints using agro-waste based flux as against the use of conventional fluxes.

2.5.2 Tensile characteristics of welded steel joints

The response of a welded joint when exposed to tension has also been of key interest. Samson et al. [40] carried out a comparative analysis of the tensile abilities of weldment of mild steels using eggshell and coconut shells in various compositions. The varied compositions were 100%, 70% and 30% for the two agrowastes materials selected (Table 10). The study results showed that 100% eggshell flux was preferable for withstanding tensile stress with a maximum tensile stress (MTS) of 850.2N compared with other compositions with reduced values of MTS.

2.5.3 Metallographic analyses

The microstructural analysis of a welded joint could give vital information about the integrity of the weld carried on steel. It could also help in the analyses of the heat affected zone (HAZ) of a welded joint. The microstructure of a welded area is a very vital part that may affect steel materials during welding. A series of phase changes most often occurs and eventually impacts negatively on mechanical properties such as hardness and toughness of the welded joint. As reported by Mohyla et al. [8] who analyzed the properties of welded joints of stainless-steel tubes, there was a phase change in the structure of the steel material when the base metal and the HAZ was inspected (Figure 6). They reported a transformation from the initial austenitic structure of the material to a new phase. Their results also showed rupture taking place around the HAZ signifying a reduced hardness value in that region.

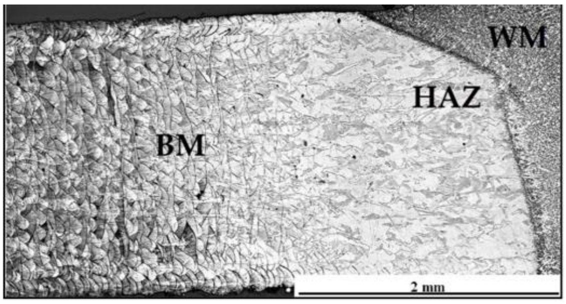

Figure 6. Welded joint of a stainless tube showing HAZ, base metal (BM) and welded region (WM) [8]

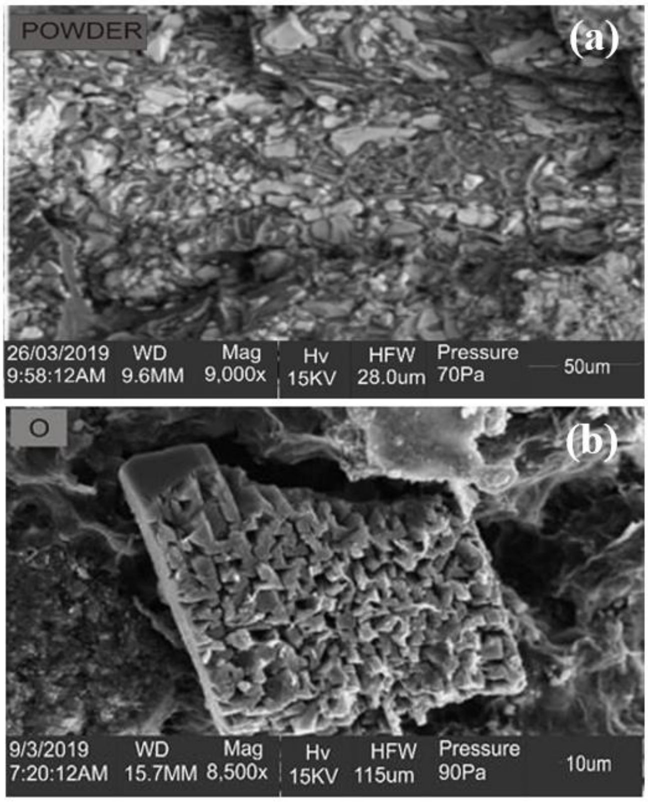

Figure 7. SEM micrograph of (a) imported flux (b) developed flux [48]

From the experimental analysis of Ogedengbe et al. [48], the microstructure study reveals the emergence of a distinctive lamellar alternating structure, whereby the produced flux's SEM micrograph displays a homogeneous structural surface and a radial pattern. Friction-induced heat may result in a distinct surface structure for the developed flux. It appears that the microstructure has an impact on the mechanical characteristics of the joints that is referred to as being significant (Figure 7).

As shown in Figure 8(b), the presence of carbon (dark particles) scattered around the welded joints developed from agrowastes based flux welding produced a superior weldment to that produced without agrowastes based flux (Figure 8(a)). Comparing the welds made with the control flux powder with those made without any flux powder, it was discovered that the weld made using the nano- flux was more ductile, had a higher maximum tensile strength, and could sustain greater loads.

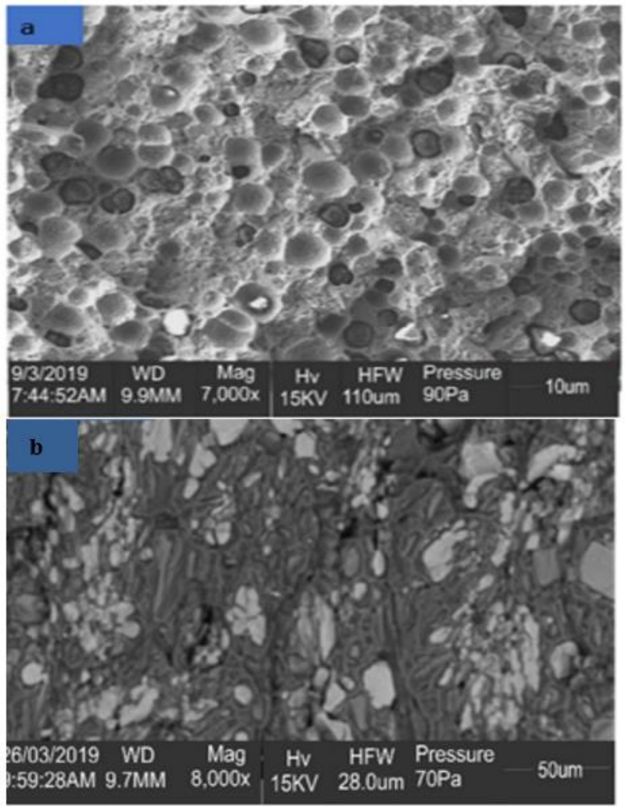

Figure 8. SEM micrographs of steel welded joints (a) without agrowastes based flux (b) with agrowastes based flux [9]

2.6 Future trends

Looking forward, future trends in biomass flux properties are poised to focus on optimizing efficiency, sustainability, and scalability across diverse applications. This includes refining biomass processing technologies, improving yield and quality of biomass products, and exploring new biomass sources and treatments [89]. Key gaps in the literature and future research perspectives include a deeper understanding of biomass variability across different feedstocks, locations, and processing methods, as well as comprehensive assessments of long-term environmental and economic impacts, including lifecycle assessments and carbon footprints [90]. Additionally, integrating advanced technologies like artificial intelligence (AI), machine learning (ML), and process modeling presents opportunities to enhance the optimization and predictive capabilities of biomass flux properties. A few of such trends includes.

2.6.1 Flux ingredient optimization

The quality of the weldment is of top priority during welding. Hence it is paramount to establish and optimize the various ingredients that make up the fluxes being produced. It is expected that future research will begin to focus on the optimization of flux producing ingredients, so as to greatly enhance the weldment qualities thereby reducing the possibility of its rapid failure.

2.6.2 Integration of advanced technology and automation of process

Recent advancements in technology had resulted in the development of safer and better ways for executing many processes. These could pose an advantage for welding technology if maximized [91]. The adaptation of weldment formation via automated processes could further enhance the characteristics of the weldment and the steels at large. Future studies could be carried out in this regard to determine how such characteristics could be enhanced [92]. The use of Artificial intelligence could give a major boost to the world of welding technology if properly adopted.

2.6.3 Biomaterial intervention

In recent times, scientists have begun to study the possibility of usage of biomaterials such as bio-wastes, etc. for welded steel enhancement [93-95]. Although some interesting results have been announced, the use of biomaterials for flux development isn't still prominent. It's expected that in a short while, this aspect will be given more attention and much more possibilities will be unraveled [96-99]. This is particularly of much interest as it will help in the achievement of SDG goals by aiding the conversion of waste to wealth. It would also help achieve a cleaner environment for all.

3. CONCLUSION

The review highlighted the diverse applications of agrowastes for flux development. It can be deduced that the three innovatively formulated flux materials, namely date seed powder, palm kernel shell (PKS), and banana peel, exerted discernible influences on the strength of the joint and the overall efficacy of the welding process, each manifesting distinctive effect. The principal determinant of these effects, elucidated through X-Ray Fluorescence (XRF) and Atomic Absorption Spectroscopy (AAS) analyses, was identified to be the unique elemental composition of each flux material. Consequently, the encompassing the development and characterization of flux derived from date seed, palm kernel shell, and banana peels; the welding of mild steel and high carbon steel utilizing the developed flux; and the assessment of the strength and durability of the welded joints employing XRF and AAS techniques, were successfully realized. The process of welding results in changes to the properties of the materials, as demonstrated by the welded joint's increased hardness when compared to the base metal. Different flux types have varying degrees of hardness, which suggests that the choice of flux material can affect the outcome of the welding process. The regions where the material underwent thermal changes during welding are highlighted by the hardness values in the heated region, which also suggest possible heat-affected zone effects. Review indicate that date seeds and palm kernel shells exhibit superior reinforcement capabilities, rendering them more suitable for augmenting the performance of various steel types in comparison to banana peels. The practicability of domestic production of agro-waste is feasible to enhance the strength of welded joint.

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