OCCUPATIONAL HEALTH AND SAFETY IN UTILIZATION OF LIGNOCELLULOSIC BIO-POZZOLANS IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

Lignocellulosic bio-pozzolans (LBPs) are either produced by open-air incineration or as industrial byproducts and can be used for soil stabilization and in making concrete for road construction. The preparation of the LPBs involves the collection of raw materials/wastes, drying, incineration, grinding, and sieving to a required size before utilization for construction works or products. The finer the LBPs, the more reactive they become, and the higher the potential binding properties. Coarse LBPs are less reactive; and therefore, exhibit low binding properties with reactions. Very fine LBPs are essentially nanomaterials and can be an occupational health and safety hazard to workers handling these materials. In this review, the LBPs production process was briefly clarified, and potential hazards and risks were investigated. Silicon Dioxide (SiO₂), the main chemical compound present in LBPs, was noted to potentially have a significant health hazard to humans. SiO₂ exposure is reported to induce deoxyribonucleic acid (DNA) destruction. This study recommends an airborne exposure limit of 2mg/m³ for LBPs, and the ACGIH exposure limit recommendation for SiO₂.

Keywords: Bio-Pozzolans, Cement, Construction, Lignocellulosic Nanomaterials, Occupational Health, and Safety
INTRODUCTION

Occupational Safety and Health (OSHA) at work are vital elements for a decent job, as contended by the International Labour Organisation (ILO). Occupational accidents have a trivial human, social and economic cost, which should be eliminated by ensuring that all workplaces are safe. According to the ILO’s latest data on annual fatal casualties from a number of countries, the United States recorded the highest number of fatal casualties (Figure 1) while Cuba recorded the highest number of calendar days during which workers were temporarily incapacitated and unable to work due to fatal injuries (Figure 2) (ILO, 2022). Norway was the least with zero days lost (2019), while the United States had 9 days lost (2014).

Significant fatal injuries and the subsequent loss of working days, have led most countries to develop and ratify occupational health and safety regulations. These include regulations for the safety and health of workers in the construction industry (Rubio et al., 2023). Occupational health and safety continuous improvement (OHSCI) in modern construction is important (Alkaissy et al., 2022; Araújo et al., 2022; Mavroulidis et al., 2022; Mohandes et al., 2022)

This is especially important while undertaking civil engineering works, which involve the use of cement and other cementitious materials. Conventional cement production, transportation, and usage lead to significant production of greenhouse gases such as CO$_2$, and now there are increased calls to reduce CO$_2$ emissions. However, it is essential to note that efforts are being made to study and develop alternative cement with a low CO$_2$ footprint (Abdalla et al., 2022; Caronge et al., 2022; Cormos, 2022; Kremer et al., 2022; Majchrzak-Kucęba et al., 2022; Nie et al., 2022; Santos et al., 2022; Syahida Adnan et al., 2022; Türkeli et al., 2022; Wang et al., 2022; Wang et al., 2022; Zhuang et al., 2022).

Other ways of reducing CO$_2$ from cement manufacturing include research on a laboratory and pilot scale to study supplementary cementitious materials (SCMs) that can potentially replace the use of conventional cement in construction. The SCMs are proven environmentally friendly materials. Some of these SCMs are the lignocellulosic bio-pozzolans (LBPs) produced through open-air incineration. They include Rice Husk Ash (RHA) (Jittin and Bahurudeen, 2022; Mohamed et al., 2022) which can be used in various construction applications like soil stabilization for road works, production of concrete and associated concrete products like concrete blocks, bricks, and paving blocks.

The preparation of the LBPs involves collecting raw materials/wastes, drying, incineration, grinding, and sieving to a required size before utilization. Generally, the finer the LBPs, the more reactive they become, and the higher the pozzolanic properties. Coarse LBPs are less reactive and have low and slow reactive pozzolanic properties.

Very fine LBPs are essentially nanomaterials and hence pose a health risk to both the researchers and the user of these materials. Tetley (2007) observed that the material composition of LBPs might have negative health impacts on human organs like the lungs, brain, and liver.

It is further noted that LBPs contain substances listed as hazardous by the International Agency for Research on Cancer (IARC). There is no universal standard for monitoring the exposure of both researchers and workers to these dangerous substances. This paper briefly explains the LBPs production process, highlights the chemical composition and classification of LBPs, and identifies and discusses the main hazardous substances in LBPs. It also provides recommendations for both exposure limits and reduction of exposure to hazards contained in these materials. Data compiled in this paper will significantly contribute to safeguarding the health of
researchers undertaking studies on the application of LBPs in construction works. It will also enhance the safety and health of workers that will handle and apply LBPs in actual construction works.

LIGNOCELLULOSIC BIO-POZZOLANS (LBPS) PRODUCTION, COMPOSITION AND CLASSIFICATION

PRODUCTION
Figure 3 shows the general LBPs production process, which requires minimal mechanization. Open-air LBPs production involves collecting raw materials which can be ordinary agricultural wastes. These are then sun-dried to ensure minimal moisture content for ease of burning. The material is burnt in the open air on a hard surface to enable the accumulation of ashes. The ashes are then left to cool. The cooling time depends on the amount of ash and environmental conditions like humidity, wind, and temperature. After cooling, the material is ground and then sieved to a recommended sieve size before being used as a pozzolanic material for making concrete or concrete products like blocks or soil stabilization.

COMPOSITION
The chemical composition of some of the LBPs from different plants and different research is detailed in Table 1 (Aluga and Kambole, 2020). The main chemical compound in LBPs is silicon dioxide (SiO2), followed by calcium oxide (CaO), as shown in Figure 4, derived from Table 1. Sodium Oxide forms about 1% of the LBPs. The LBPS also contain negligible chemical compounds such as Phosphorus pentoxide (P2O5), Manganese Oxide (Mn2O3), Titanium Oxide (TiO2), and Calcium Carbonate (CaCO3).

Figure 1: Latest Fatal casualties reported annually (IARC, 2022)
Figure 2: Lost working days annually due to fatal injuries (IARC, 2022)
Figure 3: Activities involved in LBPs production.

Figure 4: The main chemical compounds in LBPs
Table 1: Chemical composition of some of the LBPs from different plants compiled from various sources (Aluga and Kambole, 2020)

| Organic Residue     | SiO₂  | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | Na₂O | K₂O  | SO₃ | P₂O₅ | MnO₂ | TiO₂ | CaCO₃ | LOI* | SG* |
|---------------------|-------|-------|-------|------|------|------|------|-----|------|------|------|-------|------|-----|
| Bamboo Leaf         | 75.9  | 4.13  | 1.22  | 7.47 | 1.85 | 0.21 | 5.62 | -   | -    | -    | -    | -     | -    | -   |
| Barley Husk         | 31.7  | 1.55  | 2.01  | 7.61 | 0.05 | 0.01 | 27.77| 1.76| 23.21| -    | -    | -     | -    | -   |
| Bitch Bark          | 4.38  | 0.55  | 2.24  | 69.06| 5.92 | 1.85 | 8.99 | 2.75| 4.13 | 0.13 | -    | -     | -    | -   |
| Cassava Peels       | 36.7  | 3.10  | 2.50  | 8.20 | 2.9  | 1.37 | 18.74| 1.52| -    | -    | -    | -     | 15.10| -   |
| Coconut Shell       | 20.7  | 5.75  | 15.48 | 4.98 | 1.89 | 0.95 | 0.83 | 0.71| 0.32 | 0.81 | -    | -     | 11.94| -   |
| Common Thatching Grass | 17.7 | 1.41  | 0.73  | 6.18 | 1.69 | -    | 14.29| 1.34| 0.59 | 0.08 | -    | -     | 2.62 | -   |
| Corn Cob            | 66.3  | 7.48  | 4.44  | 11.57| 2.06 | 0.41 | 4.92 | -   | -    | -    | -    | -     | 1.30-1.47| - |
| Cow Dung Ash        | 65.8  | 4.46  | 3.16  | 12.98| 2.02 | 0.51 | 2.83 | 0.94| 1.38 | 0.60 | 0.37 | 23.18 | 12.28| 2.55|
| Date Palm           | 35.9  | 0.65  | 0.78  | 13.04| 6.36 | 3.60 | 7.40 | -   | -    | -    | -    | -     | 8.41 | -   |
| Forest Residue      | 20.6  | 2.99  | 1.42  | 47.55| 7.2  | 1.6  | 10.23| 2.91| 5.05 | 0.4  | -    | -     | -    | -   |
| Groundnuts Shell    | 26.9  | 5.82  | 0.50  | 9.5  | 5.60 | 1.15 | 20.02| 1.86| 2.0  | 0.32 | 0.69 | -     | 22   | -   |
| Oil Palm Shell      | 63.6  | 1.6   | 1.4   | 7.6  | 3.9  | 0.1  | 6.9  | -   | -    | -    | -    | -     | 9.6  | -   |
| Orange Peels        | 23.7  | 2.28  | 1.66  | 30.11| 4.01 | 0.37 | 24.46| 0.31| 2.50 | 0.32 | 0.34 | -     | 9.67 | -   |
| Paper Mill Sludge   | 25.7  | 4.09  | 2.26  | 9.98 | 5.80 | 0.08 | 0.11 | -   | -    | -    | -    | -     | 4.67 | -   |
| Pine Bark           | 9.2   | 7.2   | 2.79  | 56.83| 6.19 | 1.97 | 7.78 | 2.83| 5.02 | 0.19 | -    | -     | -    | -   |
| Material         | LOI* | SG* | AJHSE 3(2) | Aluga & Kambole, 2022 |
|------------------|------|-----|------------|------------------------|
| Pine Chips       | 68.1 | 7.04| 5.45       | 7.89                   |
| Poplar           | 3.87 | 0.68| 1.16       | 57.33                  |
| Poplar bark      | 1.86 | 0.62| 0.74       | 77.31                  |
| Rice Husk        | 93.2 | 0.4 | 0.1        | 1.1                    |
| Sawdust          | 67.2 | 4.09| 2.26       | 9.98                   |
| Sewage Sludge    | 50.6 | 12.8| 7.21       | 1.93                   |
| Sorghum Husk     | 49.5 | 7.95| 14.94      | 10.1                   |
| Spruce Bark      | 6.13 | 0.68| 1.9        | 72.39                  |
| Spruce Wood      | 49.3 | 9.4 | 8.3        | 17.2                   |
| Sugarcane Bagasse| 66.2 | 15.10| 3.40      | 3.75                   |
| Sugarcane Straw  | 59.0 | 4.75| 3.18       | 19.59                  |
| Tobacco Waste    | 17.0 | 3.23| 3.47       | 63.77                  |
| UFTRHA           | 80.1 | -   | 13.70      | 0.48                   |
| Vetiver Grass    | 57.4 | 3.73| 1.71       | 5.45                   |
| Wheat Straw      | 54.2 | 4.55| 1.05       | 12.54                  |
| Wood residue     | 53.1 | 12.64| 6.24      | 11.06                  |

**Key:**
- LOI* - Loss of Ignition
- SG* - Specific Gravity
Classification
LBPs are classified according to their chemical composition. There is no specific standard for the classification of LBPs. However, researchers have adopted the American Society for Testing and Materials (ASTM) C 618-91 (Shon et al., 2013). LBPs with SiO$_2$+Al$_2$O$_3$+Fe$_2$O$_3$ of more than 70% are classified as N-Class if SO$_3$ is less than 4%, while F class is for LBPS with SO$_3$ between 4-5%. The LBP is C-Class if the SiO$_2$+Al$_2$O$_3$+Fe$_2$O$_3$ is 50% or less.

OCCUPATIONAL EXPOSURE TO LIGNOCELLULOSIC BIO-POZZOLANS (LBPS) MAIN SUBSTANCES
The main compounds/substances in the LBPs from Table 1, which are health hazards in case of occupational exposure include Silicon Dioxide (SiO$_2$), Calcium Oxide (CaO), Potassium Oxide (K$_2$O), Aluminum Oxide (Al$_2$O$_3$), Iron Oxide (Fe$_2$O$_3$), Magnesium Oxide (MgO) and Sodium Oxide (Na$_2$O).

Table 2 details the occupational hazards and exposure limits to (LBPs) and suggests the exposure reduction of the above-named seven (7) substances found in the LBPs. Accordingly, the LBPs affect humans when breathed in due to occupational exposure. The following are some of the health and other effects identified when exposed to LBPs:

a) Breathing irritates the lungs
b) Repeated exposure irritates the nose.
c) LBPs can be corrosive, especially on flexible roads
d) Repeated exposure can cause lung damage

Silicon Dioxide (SiO$_2$) has a significant main effect on humans, as it is known to cause severe DNA destruction according to (Yan et al., 2020). At the same time, it’s the main compound that makes LBPs have pozzolanic properties. Other compounds such as Sodium Oxide (Na$_2$O) have no known effects on humans and are not classified as hazardous materials.

The workplace exposure to these compounds differs from one compound to another, as detailed in Table 2. Wearing respirators, putting on protective work clothing, regular bathing after using the substance, and detailed warning information in the work area are some methods suggested for limiting exposure to LBPs.
### Table 2: Occupational hazards and exposure limits to (LBPs) main compounds

| Substance                  | Hazard Summary                                                                                                                                                                                                                                                                                                                                 | Exposure Limits                                                                                       | Reduction of Exposure                                                                                                                                                                                                 | Reference                                                                                                                                                                                                 |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Silicon Dioxide (SiO₂)     | It’s recognized by the American Conference of Governmental Industrial Hygienists (ACGIH) and the International Agency for Research on Cancer (IARC) as a hazardous substance.                                                                                                                                  | ACGIH limit - 2mg/m³ (8-Hour).                                                                         | Wearing respirators where there is no local ventilation. Putting on protective work clothing. Regular washing while using the substance. Elaborate warning information in the work area. | (ACGIH, 2022; CDC, 2022; IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022; Rauf et al., 2021; Scientific, 2012; Sun et al., 2018; ThermoFischer, 2020) |
| Calcium Oxide (CaO)        | Listed as a hazardous substance by the Occupational Safety and Health Administration (OSHA), ACGIH, National Institute of Occupational Safety, Health (NIOSH) (IARC), and National Fire Protection Association (NFPA) Listed by the Department of Transport (DOT) as a corrosive chemical. | OSHA - limit 5mg/m³(8-Hour). NIOSH – limit 2mg/m³ (10-hour). ACGIH- 5mg/m³ (8-Hour)                    | Same as those reported for Silicon Dioxide (SiO₂).                                                                                                                          | (ACGIH, 2022; IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)(NFPA, 2022) |
| Potassium Oxide (K₂O)      | OSHA regulated Hazardous substance by ACGIH, NIOSH, IARC, and NFPA.                                                                                                                                                                                                                                                                     | OSHA-limit 5mg/m³ - 8-hour NIOSH – limit 2mg/m³ over a 10-hour.                                      | The same as those reported for Silicon Dioxide (SiO₂).                                                                                                                      | (ACGIH, 2022; IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)                                                                                     |
| Aluminium Oxide (Al₂O₃)    | Chronic occupational exposure causes conjunctivitis, pharyngitis, and nasal irritation. Occupational asthma might be reported. Chronic inhalation may cause pneumoconiosis.                                                                                                               | -OSHA – 15 mg/m³ total dust, 5 mg/m³ respirable fraction -ACGIH Threshold Limit Value (TLV): 10 mg/m³ | The same as those reported for Silicon Dioxide (SiO₂).                                                                                                                      | (ACGIH, 2022; CDC, 2022; IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)                                                                                     |
| Substance            | Hazard Summary                                                                 | Exposure Limits                                      | Reduction of Exposure                               | Reference                                                                                   |
|----------------------|--------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|---------------------------------------------------------------------------------------------|
| Iron Oxide (Fe$_2$O$_3$) | Regulated by OSHA  
Listed as a hazardous substance by ACGIH, NIOSH, and IARC. | OSHA-5mg/m$^3$ averaged over an 8-hour  
NIOSH - 2mg/m$^3$ over a 10-hour.  
ACGIH - 5mg/m$^3$ averaged over an 8-hour | Same as those reported for Silicon Dioxide (SiO$_2$). | Scientific, 2012; ThermoFischer, 2020)                                                          |
| Magnesium Oxide (MgO) | Similar effects as those reported for Silicon Dioxide                           | OSHA-PEL is 5mg/m$^3$ over an 8-hour.  
NIOSH - 2mg/m$^3$ over a 10-hour.  
ACGIH - 5mg/m$^3$ averaged over an 8-hour. | Same as those reported for Silicon Dioxide (SiO$_2$). | (IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)           |
| Sodium Oxide (Na$_2$O) | Considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200). | Does not contain any hazardous materials.              | Same as those reported for Silicon Dioxide (SiO$_2$). | (ThermoFischer, 2020)                                                                     |
CONCLUSION
The LBPs production process is labor-intensive despite containing potentially hazardous substances. Therefore, health and safety should be a high priority during the LBPs production and handling by researchers and everyone in close contact with these materials. The study findings are as follows:
1. Silicon Dioxide (SiO2) can have a significant health effect on humans; paradoxically, it’s the primary compound for the pozzolanic properties of LBPs.
2. Breathing in of LBPs irritates the lungs, causing coughing and shortness of breath.
3. Repeated exposure to LBPs irritates the nose.
4. LBPs can be corrosive due to their chemical composition.
5. Repeated exposure to LBPs can cause lung damage.

The following measures can be considered to prevent exposure to hazardous compounds while in contact with the LBPs:
1. Using ventilators while working with LBPs.
2. Using breathing protection at all times while working with LBPs.
3. Putting on protective gloves and clothing while working with LBPs. The clothing should not be taken home.
4. Wearing a face shield or eye protection is recommended.
5. Not eating, drinking, or smoking whilst working with LBPs.

RECOMMENDATIONS
The recommended airborne exposure limit for LBPs should be 2mg/m³. This is arrived at considering that silicon dioxide, the primary chemical compound in LBPs, has an ACGIH exposure limit recommendation of 2mg/m³.

CONFLICTING INTERESTS
No conflicting interests in this work.

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### ABBREVIATIONS

| Abbreviation | Description |
|--------------|-------------|
| ACESM        | Africa Centre of Excellence for Sustainable Mining |
| ACGIH        | American Conference of Governmental Industrial Hygienists, |
| CBU          | Copperbelt University |
| CDC          | Centers for Disease Control and Prevention |
| DOT          | Department of Transport |
| IARC         | International Agency for Research on Cancer |
| ILO          | International Labour Organisation |
| LBPs         | Lignocellulosic Bio-Pozzolans |
| LOI          | Loss of Ignition |
| NFPA         | National Fire Protection Association |
| NIOSH        | National Institute of Occupational Safety and Health, |
| OSHA         | Occupational Safety and Health Administration |
| PEL          | Permissible Exposure Limit |
| RHA          | Rice Husk Ash |
| SCMs         | Supplementary Cementitious Materials |
| SG           | Specific Gravity |
| TLV          | Threshold Limit Value |
| UFTRHA       | Ultrafine Treated Rice Husk Ash |
| DNA          | Deoxyribonucleic Acid |
| OHSCI        | Occupational health and safety continuous improvement |