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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 (SiO_2), the main chemical compound present in LBPs, was noted to potentially have a significant health hazard to humans. SiO_2 exposure is reported to induce deoxyribonucleic acid (DNA) destruction. This study recommends an airborne exposure limit of 2mg/m^3 for LBPs, and the ACGIH exposure limit recommendation for SiO_2.

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 LPBs 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. TheLBPS also contain negligible chemical compounds such as Phosphorus pentoxide (P_2O_5), Manganese Oxide (Mn_2O_3), Titanium Oxide (TiO_2), and Calcium Carbonate ($CaCO_3$).

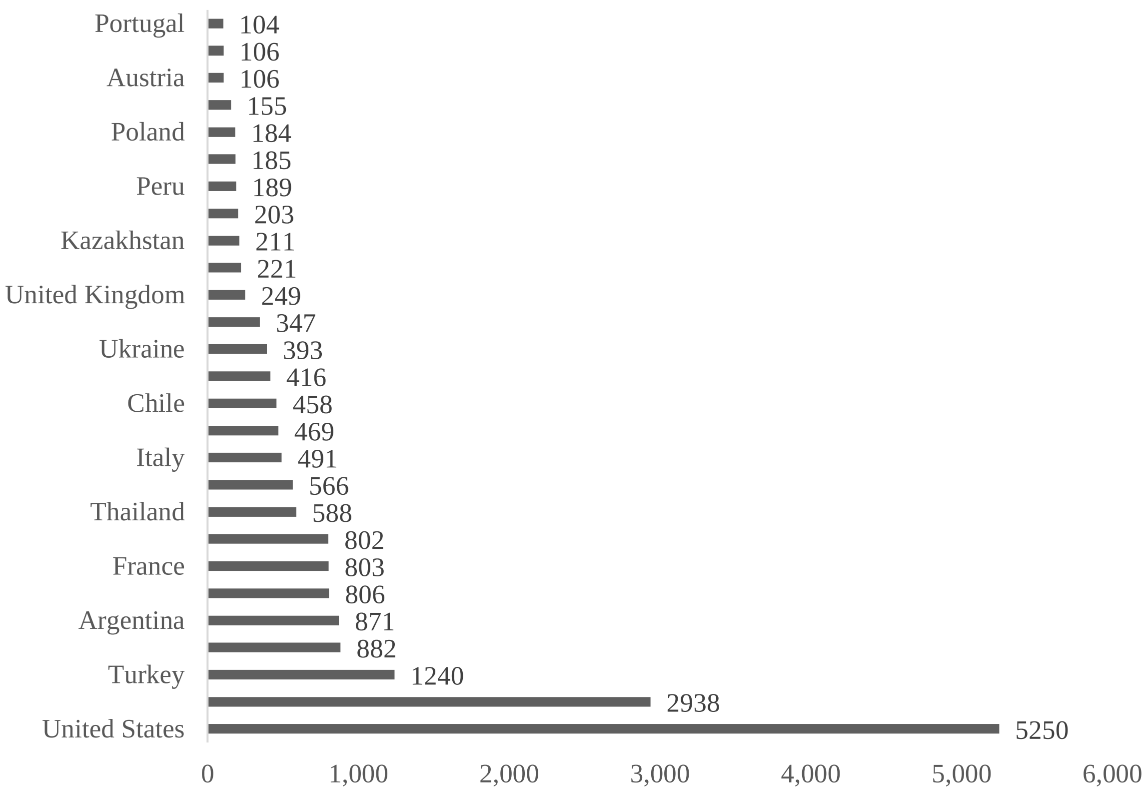

Figure 1: Latest Fatal casualties reported annually (IARC, 2022)

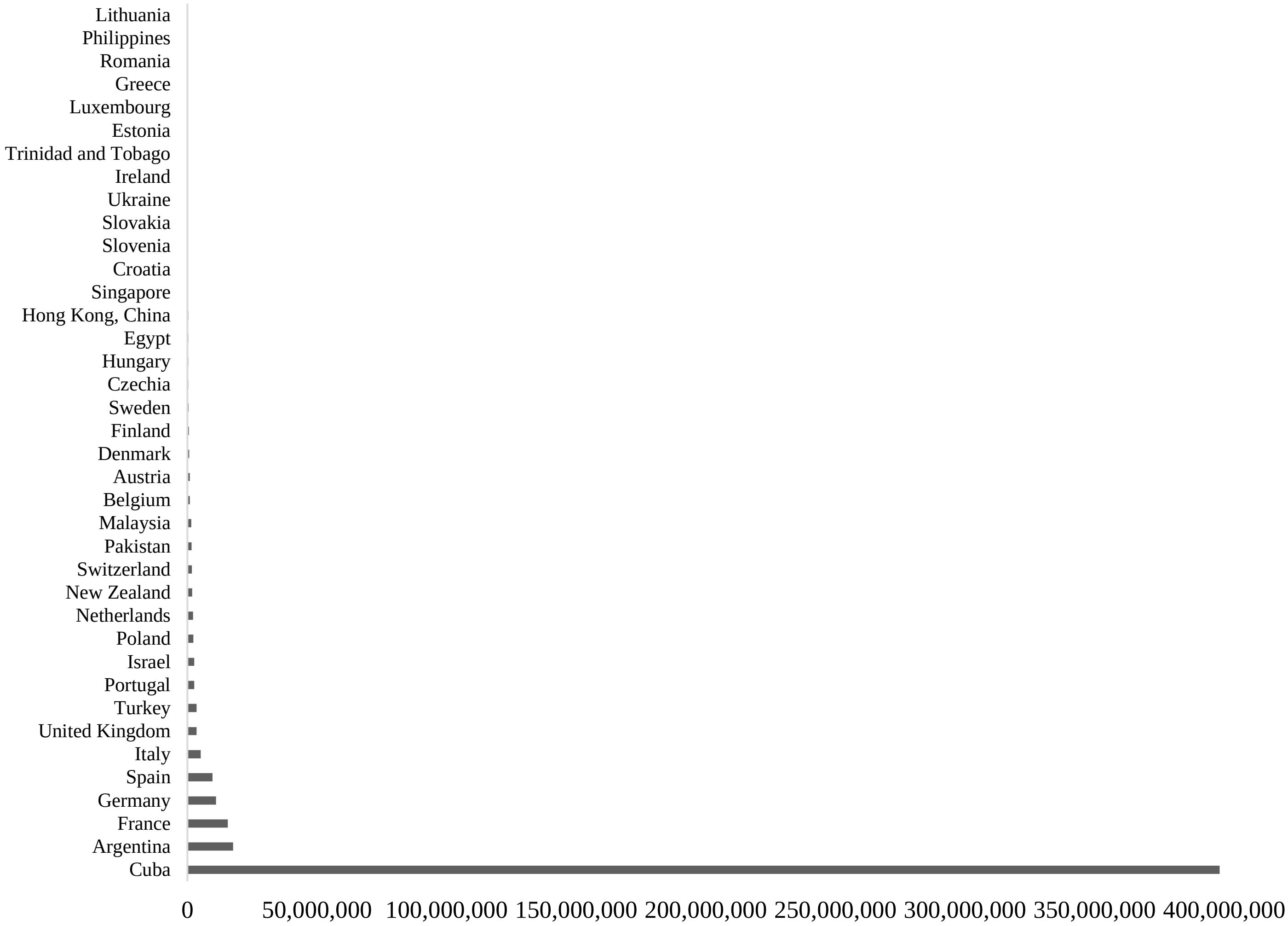

Figure 2: Lost working days annually due to fatal injuries????? (IARC, 2022)

Figure 3: Activities involved in LBPs production.

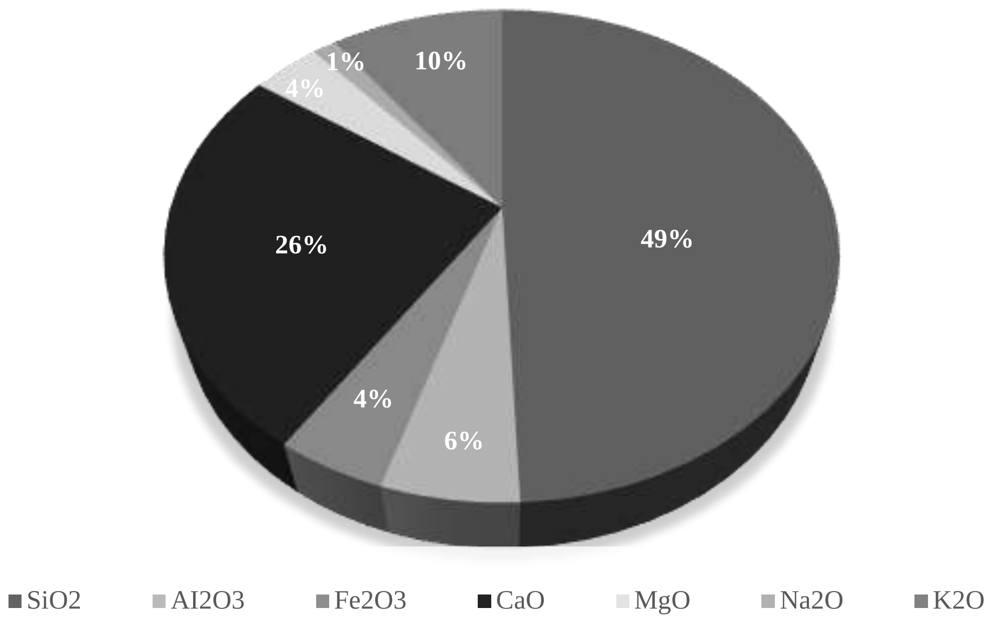

Figure 4: The main chemical compounds in LBPs

Table 1: Chemical composition of some of the LBPs from different plants compiled from various sources (Aluga and Kambole, 2020)

Organic Residue	SiO_2	AI_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	P_2O_5	Mn_2O_3	TiO_2	$CaCo_3$	LOI*	SG*
Bamboo Leaf	75.90	4.13	1.22	7.47	1.85	0.21	5.62	-	-	-	-	-	-	-
Barley Husk	31.77	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	36.79	3.10	2.50	8.20	2.9	1.37	18.74	1.52	-	-	-	-	15.10	-
Coconut Shell	20.70	5.75	15.48	4.98	1.89	0.95	0.83	0.71	0.32	0.81	-	-	11.94	-
Common Thatching Grass	17.76	1.41	0.73	6.18	1.69	-	14.29	1.34	0.59	0.08	-	-	-	2.62
Corn Cob	66.38	7.48	4.44	11.57	2.06	0.41	4.92	-	-	-	-	-	1.30-1.47	-
Cow Dung Ash	65.87	4.46	3.16	12.98	2.02	0.511	2.83	0.94	1.38	0.60	0.37	23.18	12.28	2.55
Date Palm	35.93	0.65	0.78	13.04	6.36	3.60	7.40	-	-	-	-	-	8.41	-
Forest Residue	20.65	2.99	1.42	47.55	7.2	1.6	10.23	2.91	5.05	-	0.4	-	-	-
Groundnuts Shell	26.96	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	23.72	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	25.70	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	-	-	-

Pine Chips	68.18	7.04	5.45	7.89	2.43	1.2	4.51	1.19	1.56	-	0.55	-	-	-
Poplar	3.87	0.68	1.16	57.33	13.11	0.22	18.73	3.77	0.85	-	0.28	-	-	-
Poplar bark	1.86	0.62	0.74	77.31	2.36	4.84	8.93	0.74	2.48	-	0.12	-	-	-
Rice Husk	93.2	0.4	0.1	1.1	0.1	0.1	1.3	-	-	-	-	-	3.7	-
Sawdust	67.20	4.09	2.26	9.98	5.80	0.08	0.11	-	-	-	-	-	4.67	-
Sewage Sludge	50.6	12.8	7.21	1.93	1.48	0.32	1.70	-	-	-	-	-	-	-
Sorghum Husk	49.5	7.95	14.94	10.1	0.49	-	9.46	0.00	2.45	-	1.12	-	-	-
Spruce Bark	6.13	0.68	1.9	72.39	4.97	2.02	7.22	1.88	2.69	-	0.12	-	-	-
Spruce Wood	49.3	9.4	8.3	17.2	1.1	0.5	9.6	2.6	1.9	-	0.1	-	-	-
Sugarcane Bagasse	66.28	15.10	3.40	3.75	0.51	1.55	5.15	1.45	-	-	-	-	-	-
Sugarcane Straw	59.06	4.75	3.18	19.59	2.25	0.73	4.75	-	-	-	-	-	2.05	-
Tobacco Waste	17.03	3.23	3.47	63.77	2.65	-	0.21	3.30	0.05	0.05	0.38	-	5.67	-
UFTRHA	80.10	-	13.70	0.48	0.89	-	2.07	-	2.12	0.24	-	-	-	-
Vetiver Grass	57.48	3.73	1.71	5.45	1.24	0.12	15.49	-	-	-	-	-	11.76	-
Wheat Straw	54.24	4.55	1.05	12.54	2.39	-	-	-	-	-	-	-	7.22	-
Wood residue	53.15	12.64	6.24	11.06	3.06	4.47	4.85	1.99	1.37	-	0.57	-	-	-

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 $SiO_2+Al_2O_3+Fe_2O_3$ 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 $SiO_2+Al_2O_3+Fe_2O_3$ 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_2O), Aluminum Oxide (Al_2O_3), Iron Oxide (Fe_2O_3), Magnesium Oxide (MgO) and Sodium Oxide (Na_2O).

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 in 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_2O) 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 (SiO_2)	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/m^3 (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/m^3(8-Hour). **NIOSH** – limit 2mg/m^3 (10-hour). ACGIH- 5mg/m^3 (8-Hour)	Same as those reported for Silicon Dioxide (SiO_2).	(ACGIH, 2022; IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)(NFPA, 2022)
Potassium Oxide (K_2O)	OSHA regulated Hazardous substance by ACGIH, NIOSH, IARC, and NFPA.	OSHA-limit 5mg/m^3 - 8-hour NIOSH – limit 2mg/m^3 over a 10-hour.	The same as those reported for Silicon Dioxide (SiO_2).	(ACGIH, 2022; IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)
Aluminium Oxide (Al_2O_3)	Chronic occupational exposure causes conjunctivitis, pharyngitis, and nasal irritation. Occupational asthma might be reported. Chronic inhalation may cause pneumoconiosis.	-OSHA – 15 mg/m^3 total dust, 5 mg/m^3 respirable fraction -ACGIH Threshold Limit Value (TLV): 10 mg/m^3	The same as those reported for Silicon Dioxide (SiO_2).	(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
				Scientific, 2012; ThermoFischer, 2020)
Iron Oxide (Fe_2O_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).	(IARC, 2022; New Jersey Department of Health and Senior Services, 2007; OSHA, 2022)
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 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_2O)	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/m^3. This is arrived at considering that silicon dioxide, the primary chemical compound in LBPs, has an ACGIH exposure limit recommendation of 2mg/m^3.

CONFLICTING INTERESTS

No conflicting interests in this work.

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REFERENCES

Abdalla, A. A., Salih Mohammed, A., Rafiq, S., Noaman, R., Sarwar Qadir, W., Ghafor, K., AL-Darkazali, H., & Fairs, R. (2022). Microstructure, chemical compositions, and soft computing models to evaluate the influence of silicon dioxide and calcium oxide on the compressive strength of cement mortar modified with cement kiln dust. *Construction and Building Materials*, *341*, 127668. https://doi.org/10.1016/J.CONBUILDMAT.2022.127668

ACGIH. (2022). *American Conference of Governmental Industrial Hygienists*. American Conference of Governmental Industrial Hygienists. https://www.acgih.org/

Alkaissy, M., Arashpour, M., Rashidi, A., Mohandes, S. R., & Farnood, P. (2022). Simulation-based analysis of occupational health and safety continuous improvement (OHSCI) in modern construction and infrastructure industries. *Automation in Construction*, *134*, 104058. https://doi.org/10.1016/J.AUTCON.2021.104058

Araújo, L. L. F., Saldanha, M. C. W., Gohr, C. F., & Nascimento, G. H. P. (2022). Improvement factors of constructability and occupational safety on project life cycle phases. *Automation in Construction*, *138*, 104227. https://doi.org/10.1016/J.AUTCON.2022.104227

Caronge, M. A., Tjaronge, M. W., Rahim, I. R., Irmawaty, R., & Lapian, F. E. P. (2022). Feasibility study on the use of processed waste tea ash as cement replacement for sustainable concrete production. *Journal of Building Engineering*, *52*, 104458. https://doi.org/10.1016/J.JOBE.2022.104458

CDC. (2022). *The National Institute for Occupational Safety and Health (NIOSH*. The National Institute for Occupational Safety and Health (NIOSH. https://www.cdc.gov/niosh/index.htm

Cormos, C. C. (2022). Decarbonization options for cement production process: A techno-economic and environmental evaluation. *Fuel*, *320*, 123907. https://doi.org/10.1016/J.FUEL.2022.123907

IARC. (2022). *International Agency for Research on Cancer*. International Agency for Research on Cancer. https://www.iarc.who.int

Jittin, V., & Bahurudeen, A. (2022). Evaluation of rheological and durability characteristics of sugarcane bagasse ash and rice husk ash based binary and ternary cementitious system. *Construction and Building Materials*, *317*, 125965. https://doi.org/10.1016/J.CONBUILDMAT.2021.125965

Kremer, D., Strunge, T., Skocek, J., Schabel, S., Kostka, M., Hopmann, C., & Wotruba, H. (2022). Separation of reaction products from ex-situ mineral carbonation and utilization as a substitute in cement, paper, and rubber applications. *Journal of CO2 Utilization*, *62*, 102067. https://doi.org/10.1016/J.JCOU.2022.102067

Majchrzak-Kucęba, I., Wawrzyńczak, D., & Ściubidło, A. (2022). Experimental investigation into CO2 capture from the cement plant by VPSA technology using zeolite 13X and activated carbon. *Journal of CO2 Utilization*, *61*, 102027. https://doi.org/10.1016/J.JCOU.2022.102027

Martin, A. K. C. (2020). *Soil Stabilization with Selected Lignocellulosic Bio-Pozzolans for Road Construction: A Review*.

Mavroulidis, M., Vouros, P., Fotiadis, S., Konstantakopoulou, F., Fountoulakis, G., Nikolaou, I., & Evangelinos, K. (2022). Occupational health and safety of multinational construction companies through evaluation of corporate social responsibility reports. *Journal of Safety Research*, *81*, 45–54. https://doi.org/10.1016/J.JSR.2022.01.005

Mohamed, A. A. M. S., Al-Ajamee, M., Kobbail, A., Dahab, H., Abdo, M. M., & Alhassan, H.-E. (2022). A study on soil stabilization for some tropical soils. *Materials Today: Proceedings*, *60*, 87–92. https://doi.org/10.1016/J.MATPR.2021.12.260

Mohandes, S. R., Abdelmageed, S., Hem, S., Yoo, J. S., Abhayajeewa, T., & Zayed, T. (2022). Occupational Health and Safety in Modular Integrated Construction projects: The case of crane operations. *Journal of Cleaner Production*, *342*, 130950. https://doi.org/10.1016/J.JCLEPRO.2022.130950

New Jersey Department of Health and Senior Services. (2007). *Magnesium Oxide Hazard Summary*. *January*.

NFPA. (2022). *National Fire Protection Association*. https://www.nfpa.org/

Nie, S., Zhou, J., Yang, F., Lan, M., Li, J., Zhang, Z., Chen, Z., Xu, M., Li, H., & Sanjayan, J. G. (2022). Analysis of theoretical carbon dioxide emissions from cement production: Methodology and application. *Journal of Cleaner Production*, *334*, 130270. https://doi.org/10.1016/J.JCLEPRO.2021.130270

OSHA. (2022). *Occupational Safety and Health Administration, Washington: Occupational Safety and Health Administration*.

Rauf, A. U., Mallongi, A., Daud, A., Hatta, M., & Astuti, R. D. P. (2021). Ecological risk assessment of hexavalent chromium and silicon dioxide in well water in Maros Regency, Indonesia. *Gaceta Sanitaria*, *35*, S4–S8. https://doi.org/10.1016/J.GACETA.2020.12.002

Santos, T. A., Cilla, M. S., & Ribeiro, e D. v. (2022). Use of asbestos cement tile waste (ACW) as mineralizer in the production of Portland cement with low CO2 emission and lower energy consumption. *Journal of Cleaner Production*, *335*, 130061. https://doi.org/10.1016/J.JCLEPRO.2021.130061

Scientific, T. F. (2012). Safety Data Sheet . ةم سلا تانايب ةرشن Safety Data Sheet. *Material Safety Data Sheet*, *4(2)*(1), 8–10.

Sun, D., Gong, L., Xie, J., Gu, X., Li, Y., Cao, Q., Li, Q., Luodan, A., Gu, Z., & Xu, H. (2018). Toxicity of silicon dioxide nanoparticles with varying sizes on the cornea and protein corona as a strategy for therapy. *Science Bulletin*, *63*(14), 907–916. https://doi.org/10.1016/J.SCIB.2018.05.037

Syahida Adnan, Z., Ariffin, N. F., Syed Mohsin, S. M., & Abdul Shukor Lim, N. H. (2022). Review paper: Performance of rice husk ash as a material for partial cement replacement in concrete. *Materials Today: Proceedings*, *48*, 842–848. https://doi.org/10.1016/J.MATPR.2021.02.400

ThermoFischer. (2020). *Sodium Oxide*. https://www.fishersci.com/store/msds?partNumber=AA3671214&productDescription=SODIUM+OXIDE+25G&vendorId=VN00024248&countryCode=US&language=en

Türkeli, S., Huang, B., Ohnishi, S., & Kemp, R. (2022). Issues, interventions, and innovations in the cement industry: A comparative trajectory analysis of eco-cement transitions in the Netherlands, China, and Japan. *Circular Economy and Sustainability*, 545–566. https://doi.org/10.1016/B978-0-12-819817-9.00027-2

Wang, D., Xiao, J., & Duan, Z. (2022). Strategies to accelerate CO2 sequestration of cement-based materials and their application prospects. *Construction and Building Materials*, *314*, 125646. https://doi.org/10.1016/J.CONBUILDMAT.2021.125646

Wang, S., Zhu, H., Liu, F., Cheng, S., Wang, B., & Yang, L. (2022). Effects of steel fibers and concrete strength on flexural toughness of ultra-high-performance concrete with coarse aggregate. *Case Studies in Construction Materials*, *17*, e01170. https://doi.org/10.1016/J.CSCM.2022.E01170

Zhuang, S., Wang, Q., & Zhang, M. (2022). Water absorption behaviour of concrete: Novel experimental findings and model characterization. *Journal of Building Engineering*, *53*, 104602. https://doi.org/10.1016/J.JOBE.2022.104602

ABBREVIATIONS

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