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The Use of Mining and Mineral Processing Wastes as an Alternative Source of Aggregate

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Abstract

Integration of mineral waste into other applications such as concrete production is a win-win situation for the effective management of mining and mineral wastes. Search for an effective method of waste valorization a by-product for an industrial application is highly significant to the circular economy. Thus, this work carefully reviewed the various useful mineral wastes and their processing method as alternative aggregate for concrete production. From the study, it was established that a well processed mineral waste will function well in concrete production. Hence reducing the overall dependence on natural aggregates for the building and construction industries as well as reducing the environmental degradation that mining sites are subjected to during the mining activities. The information from this review will help in the promotion of the circular economy.

Keywords*: Mining, minerals, waste, processing, aggregates*

1. Introduction

Mining refers to the extraction of useful materials from the earth crust. These materials include gold, copper, coal and iron ore which is the raw material from which iron is obtained. Mining process is dated back to prehistoric period where flint is mined and used for tools and weapons since it can break into shards with sharp edges, so also is copper and gold mining, they are dared back to prehistoric times. The product of mining is known as minerals which represent a typical inorganic material with specific and definite chemical composition by percentage. It normally appears in the form of crystals and very valuable in natural form. However, they are mixed with several waste materials for several applications. An example is the mixture of minerals and rock which usually follow the mine and processed and refined into a useful mineral. Modern mining is categorized into two which include; surface mining where the ground is blasted and the ores close to the earth crust is removed and moved to processing centers known as refineries where the actual useful mineral is extracted [1-3]. Surface mining is somehow destructive especially to the surrounding landscape where large holes or pits are always formed as a result of the surface mining activities. However, underground mining, it involves removal of ore from the deeper part of the earth where the miners use tunnels to blast into the rock to access the deposits of the ores. One of the negative impacts of this mining process is accident occurrence to miners where miners are trapped in the underground. Mining career is a dangerous one because of the health problems. The dust particles could cause lung problems. An example of these problem is the black lung disease which is usually associated with mining of coal. This kind of disease causes breathing impairment. The mining, mineral processing as well as the metallurgical industries engaged in several processing that has led to excessive waste generation running into billions mg annually. Some of these wastes include dust solutions, sludges, gases and mineral materials like waste from mine leach residue and ore processing tailings, fly ash and slag. Meanwhile, it is possible to process the waste into useful products like minerals and metals which include gold, copper, uranium and titanium. Despite the progress that have been made in in the recycling of these minerals for useful applications, some important waste is still discarded and left unprocessed. These account for important loss in minerals and metals which when recovered can contribute to the need of the primary mineral and metal industries. More so, in addition to the losses, there are other social and environmental impact of the discarded waste, thus, imposing economic burden and threat to lives in the community. Hence, special attention is required to encourage the processing of waste for subsequent use [4-5] natural aggregates like sand and gravel represent one-third of materials used in the building and construction industries and these are mined largely globally. According to [6], the production of aggregates is estimated to be between 20 to 40 milliard mg. mining backfills, fine sand containing high content of silica, land macro levelling, cement and glues and asphalt are products of ground aggregates used in construction purposes. In a study by Baic et al. [7], there are recent problem with the demand for natural aggregates and to limit the cost of extraction and processing of natural waste, there is a need to invest in the processing of its aggregate sand its technology of production as well as recovery. Thus, this work focused on mineral waste as alternative aggregates for subsequent applications. In a study by [8], waste from carbon fiber was deployed in manufacturing a lightweight aggregate for concrete production about 0, 2.5,5 and 10 % by weight of pulverized carbon fiber were deployed into about 90 % of granite marble sludge and 10% of sepiolite rejection. It was reported that the mixture was milled, kneaded using water, extruded and finally shaped into pellets and oven dried and heated at varying temperature of 110, 1125 and 1150 degree centigrade at 4,8 and 16 minutes respectively using a rotary furnace. The result showed that improved mechanical properties were achieved as well as lightness. Amin et al. [9] established that the recent technology in recycling process has changed a nonrenewable resource into renewable one such as ceramic waste has been transformed into construction material. According to the study, the ceramic waste can be used to eliminate the complex problems associated with material shortage in the building and construction industry. Some of those waste is using the silica fume and metakaolin admix with cement to enhance the performance of concrete. According to the study, the percentage variation of silica fume and metakaolin ranges from 10,20 to 30 % and the mechanical and physical properties showed that they are proficient materials that can replace cement concrete. Gayana and Ram Chandar [10] reported that utilization of waste rocks from mine and tailing as constituent aggregates will improve green sustenability. This is due to the fact that natural sand is depleting in nature and iron tailings are promising replacement for this material, thus, sand in concrete must be replaced with a material which possess a property that is stronger than the existing sand as a constituent of concrete. In a study by [11], lightweight aggregates were produced from waste ornamental stone by preparing different compositions in varying proportion. Characterizations were carried out using X-ray powder diffraction, X-ray fluorescence and differential thermal analysis and scanning electron microscopy integrated with energy dispersive spectroscopy were deployed in the characterization process. The result showed that silica presence and alumina as well as the fluxes contributed to the regulation of viscosity of the liquid phase in the aggregate during the heat treatment process. There was decrease in the bulk density of the bloated aggregates as a result of the increased clay content. More so, glassy phase was observed which showed the evidence lightweight aggregates presence. In the study of [12], it was reported that about 6 % of materials utilized in the United Kingdom brick production are obtained from alternative materials which are recycled from secondary sources. However, studies are yet to capture their effective utilization. It was observed that waste materials from ceramics has grown globally over the past two decades and its utilization has not been fully explored in the UK. In a study by [13], it was reported that cemented backfill represent an effective green mining waste material process due to its advantages in the protection of the surface environment. However, mine tailings are heavily found within mine locations and they are proficient integral materials for filling cement. Consequently, alternative source of materials in aggregate is needful to put an end or reduce the overdependence in the natural aggregates. Thus, this study aimed to investigate the different minerals and processing for use in aggregates as alternative materials for constructions purposes. Hence, there will be sustainable circular economy.

2. Mining

The rapid development in the economy has increased the demand for products from minerals and this is at increasing rate. Mineral extraction from the ore can be done using two methods which are placer mining which involve the use of water and gravity to concentrate the important mineral deposits and mining of the hard rock, the rock is pulverized which contains the ore itself and the chemical compositions are related. Several billions of tons of mining waste are obtained from the mining industry annually and iron tailing represent a by-product of the iron ore which usually depends on the condition of mining [14].

[15] investigated the mechanical properties of concretes made with low sulfide mining waste by using three formulation of waste rock and varying binders which include type I OPC and type V high sulfate resistant OPC and these were selected based on the compressive strength test within 28 days curing time. Resistant of concrete to chloride ion penetration, scaling surface of the deicing salt, freezing and thawing were evaluated. Also, the tendency for waste rock expansion as aggregate was determined due to the possible attack from the alkali-silica and sulfate. The

study further established that after 91 days of curing, the result demonstrates that waste rock-based concrete has excellent mechanical properties as well as resistant to chloride iron penetration when compared to the control concrete. It was affirmed that there was maximum performance upon exposure to freezing, thawing and salt scaling apart from when the V high sulfate-resistant was applied. Furthermore, it was established that the waste rock generated expansion which could be attributed to the existence of alkali-silica. Thus, other supplementary waste materials are needed for ensuring adequate cementitious materials in concrete which enhances durability.

According to [16], the commonest material known to be fine aggregate is the river sand. However, in several part of the world, this mining of fine sand has been under restriction for the purpose of protecting the river bed, however, there is an increasing demand for an alternative fine aggregate in the construction industry. More so, studies have shown that there are also increasing by-products from industries that represent waste materials and their consistent disposal in the environment has constituted some environmental health hazards, thus, industrial waste materials are now being considered as an alternative waste material in fine aggregates in concrete production. To this end, this study considered the review of fifteen different by-product of industrial wastes as possible alternatives aggregate for construction purposes. Their characteristics which reflects the actual properties of concrete were studied. Such properties include compressive strength, drying shrinkage, workability water absorption, permeability of the chloride, ultrasonic pulse velocity. The result showed that the maximum replacement level for steel slag is 20% and the same for copper slag, as well as granite dust. However, for bottom ash and crushed rock aggregates, the replacement level stand at 40%. More so, there was decrease in the workability due to high water absorption while an increased carbonation was observed for all the aggregates. The use of recycled ceramic and copper slag helped in enhancing the abrasion resistance of the concrete. Figure 1 showed the morphologies of the different fine aggregates as examined in the study.

Figure 1: Morphology of fine aggregates

Source: [16]

Production of minerals as well as the management contribute immensely to the development of the economy, also, managing the waste from this process helps in the formation of economic strategies for future utilization of resources, hence, a way to manage the waste the coarse-grain waste from mining processes is its reuse in the building and construction industries. Thus, [17] developed an experimental method for the possibility of utilizing the waste rock as fine aggregates in geopolymers by carrying out the mechanical characterizations as well as the chemical and physical properties of the waste rock materials. The result showed that finer aggregates microstructure with evidence of homogeneity in the geopolymer matrix was achieved. It was reported that the geopolymer governed the behavior of the mixture.

Furthermore, the study established that most industrial waste rock contain some amount of acid which has limited its use in cement and concrete production. However, making use of alkali-integrated material can reduce the acidic level of the waste rock obtained from mining. Thus, the use of waste materials like fly ashes from industrial processes and waste rock mining in producing environmentally friendly geopolymers for building and construction industries has increased the depth of the sector through adequate chemical and morphological characterization. The leaching compliance result demonstrated that the mining waste rock conform with the standard of inert waste for the toxic element present. Also, chemical composition of the waste rock such as the quartz, pyrite and the minerals from clay accelerated the continuous formation of interface between fly ash based geopolymer matrix and aggregates, hence an excellent phase adhesion in the geocomposite was achieved.

In the study of Gautam et al. [18], waste mining from limestone was transformed into aggregates of varying sizes of between the range of 19 mm and 0.075 mm and used to produce bituminous concrete and dense bituminous macadam by replacing the traditional aggregates (basalt). The properties of the limestone waste were determined and used as the physical parameters for performance of the mix. More so, the evaluation was done based on the strength, durability and resistant to the moisture. The results demonstrate its suitability as a sustainable replacement material. Mining operations have negative influence on the environment and health of the people in the community. The waste usually seen from the mining are waste rocks and tailings. The waste rock is obtained from tunnel excavations and this composed of significant amount of precious minerals which is usually removed to have access to the underground deposits of ore. However, tailings are obtained from materials that have ore which is the result of mineral separation process in the plants [19].According to [20], mining operations can release significant number of toxic elements which can penetrate into the soil, air and water as well as the human food chain. More so, the environmental and health impact of the mining operation has caused the reason behind an understudy of the recovery sites. Thus, this study examined some tailings obtained from the abandoned mine site by sintering the waste to obtain a lightweight aggregate. The fraction obtained was less than 63 μm and this was mixed with about 10 % of sepiolite waste in order to gain plasticity. Furthermore, 2.5 % powdered form of thermoplastic and carbon fiber were added to examine their effects as additives. The entire mixture was then thoroughly mixed and extruded into pellets, oven dried and heat treated at 1175 degrees for about 4 minutes using a rotary kiln. Characterizations involving the properties of the aggregates were evaluated and these include; density, porosity, water absorption as well as mechanical strength. Also, microstructural and textural properties were studied. The result showed that the addition of carbon fiber led to a developed porous core characterized by a thin shell compared to when the constituents are not used. These results encouraged the continuous test of wastes as proficient material for aggregate especially for lightweight concrete.

3. Processing of Mineral waste

Clean energy technologies will help in driving the concept of low carbon economy and this will help in the growth of metal resources industries. Apart from the traditional mineral resources, wastes from the industry contain many valuable metals, although their composition is quite complex as well as their treatment which could result to severe environmental effect. Similarly, the interest in sustainable economy and development placed a demand on the need for clean and efficient economy as well as a reliable technology for the extraction of valuable metal from the available metals as well as the industrial wastes. It was reported that a proficient technique for the processing of this waste is in the use of ammonium sulfate roasting. It is environmentally friendly, low energy consumption, excellent reaction selectivity and is known to have great metal recovery capacity.

However, its application is limited by the comprehensive understanding. It was established that this technology is characterized by latest idea in the processing of industrial wastes which of excellent significance for the cleaner production environment. Figure 2 showed the process of thermal composition of the ammonium sulphate. From the Figure, it was observed that the decomposition process is in two ways where the ammonium sulphate decomposes into $(NH_4)_3H(SO_4)_2$ and decomposes again into pyrosulfate and finally into NH_3, SO_2, N_2, and H_2O. further decomposition occurred where the ammonium sulfate was decomposed into ammonium bisulfate and pyrosulfate as well. Similarly, Figure 3 depicts the procedure for mineral carbonation using the blast furnace slag. It represents the process of extracting the valuable metals using blast furnace via ammonium sulfate as well as sequestration of carbon dioxide by leaching
slag.

Figure 2: Process of thermal decomposition (Ammonium sulphate)

Source: [21]

Figure 3: Carbonation of minerals with blast furnace slag

Source: [21]

According to [22], the demand for newer technologies for renewable energy and enhancement of energy efficiency have increased with the aim of the world to trend on the path of low carbon economy. However, many of the industries depend on critical metals which refers to metal that are valuable to the society as well as capable of causing disruption. Thus, important concentrations on the critical metal increased the operations of the mining and waste processing industries. Hence, an opportunity exists when meeting critical demand and this opportunity lies in waste re-processing which have varying significant properties when running the mine ores. It implies that the process of running mine ore may be the same with the process of mineral processing procedure as well as processing of waste, however, adequate method for separation, concentration of the critical metals is quite different. Thus, the range of innovations for the separation of critical path include;

1. Liberation of mineral can be best obtained via stirred milling whereby particles are broken and the hydrophilic surface is removed to prevent the flotation of particles. Also, separation of particles based on size is done via the use of semi-inverted cyclones and hybrid classification technique

2. Separating mineral from gangue be done via flotation with fluidized bed reactors and reactor separator induced air reactor being the best for coarse and fine aggregates. In addition to this, the use of gravity concentration via the use of counter flow fluidized bed separator is good for mineral separation from gangue.

Meanwhile, it is essential to say that extraction of valuable metals from tailings is bound by the mineralogical properties. Crucial steps are needful for its valorization. Thus, deploying these technologies for the extraction of critical metals from the mining and wastes processing will not only increase the demand for metal, but enhance the need for achieving a sustainable circular mining structure with zero waste. Figure 4 showed a typical diagram depicting the different mine waste generated from a typical metal. The generation of mine waste come from the pit and underground mining operations which include that of waste rock, mining water and the overburden.

On the other hand, mineral waste processing is obtained from the concentrations of the economic metal and minerals which may be sludges, tailings and mill water. That of tailings consist of a mixture of non-economical crushed rocks and fluids processed from mill, concentrator or washery during the processing of mineral. In the case of metallurgical waste, they are generated from the result of extraction and recovery of metals from mineral concentrates which include roasted ores, ashes, flue dust, process water and leached ores. According to the study of López-Acevedo et al. [23], valuable data obtained from the country’s mine could help the detection of valuable waste metals which could be used as alternative aggregate materials for construction and other purposes.

Figure 4: Generation of mine waste from a metal

Source: [22]

In the study of Adom-Asamoah et al. [24], flexural properties of twelve different reinforced concrete beams made of phyllite coarse obtained as the by-product of underground gold mining operation. Four-point tests were carried on the beams and the experimental failure loads was averaged to be approximately 115 % of the theoretical loads. The result showed that there were early cracks in the form of shear and higher flexural crack widths that obtained at service loads.

Blast furnace slag is proficient as a material in coarse aggregates in concrete block. It is a by-product obtained from iron industry because it is a lightweight material and is produced in large quantities. From the findings, the blast furnace is known to be highly suitable as a coarse aggregate and it has a lower fraction in weight than conventional concrete made with coarse aggregate. However, there was a slight change in the strength, that is, decrease in the strength. Which implies that replacing all the natural aggregates with slag would provide lightweight blocks which represent a significant benefit for the environment as well as saving of costs [25].

Conclusion

The main wastes in mines include rock and tailings. These wastes cost a lot of environmental issues for the mining industries in the entire globe. With the increasing regulations in the restriction of natural aggregate mining, it is important to develop efficient and clean integrated techniques for managing wastes and get the valorized wastes into useful products as alternative aggregates for other applications. From this review, it was established that mine waste processing has been validated as excellent b-product for concrete production. Furthermore, blast furnace slag is also very viable product for coarse concrete production. Thus, effective management of mine wastes and its processing will help in effective management of the circular economy.

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