Characteristics and utilization of Jarosite and fly ash wastes in the construction industry: an overview

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Abstract-
Worldwide, there is a daily production of wastes include fly ash and jarosite which can have a detrimental effect on the environment. Many researchers have utilized fly ash and jarosite to fabricate products include bricks, concrete which are used in the construction industry. This review paper presents the characteristics of jarosite and fly ash. Furthermore, it summarizes selected studies carried out on the successful reuse of jarosite and fly ash as a component in some construction materials. It has been reported that using certain ratios in bricks and concretes made with jarosite and fly ash as constituents can display satisfactory mechanical properties such as compressive strength. Due to the high generation of wastes around the world, more studies are needed to investigate the environmental friendliness and cost-effectiveness of products made with jarosite and fly ash as a component.

Key words: Fly ash, Jarosite, Brick, Concrete, Construction, Characteristics

1. Introduction

The generation of various types of waste in the world has pushed researchers to study the potential reuse of the generated wastes. There is a high amount of wastes generated daily around the world and the main issue is their disposal. It is, therefore, important that the generated wastes include solid wastes be reuse to alleviate their negative impact. Many types of wastes include jarosite and fly ash are being generated daily. It has been reported that jarosite in among the significant solid waste material and it is generated during the hydrometallurgical zinc extraction process [1]. On the other hand, fly ash wastes are produced from the coal used for power generation [2]. Shekhovtsova et al [3] indicated that in South Africa, there is a generation of about 30 Mt and 10 Mt per year of fly ash from two main coal processing companies. They further said that the main issue is how to reuse the generated fly ash. On the other, in India every year, almost 200 million tons of fly ash is generated [4]. As for the generation of jarosite, it has been reported that about 0.25 MT is generated in India per year [5]. Many attempts have been made to reuse jarosite and fly ash as in bricks [6,7], ceramic bricks [8], concrete and paver blocks [4, 9-17], aggregates [18-21]. Furthermore, fly ash can be used as a cement replacement [22]. Compressive strength is considered as one of
the most important and useful properties for construction materials such as concrete and bricks.

This paper presents the characteristics, usage and properties with a focus on compressive strength of jarosite and fly ash in construction. It covers selected studies conducted around the world on the reuse of the two solid waste materials. It will further indicate that the successful reuse of the wastes materials would have an impact on the environment and mitigate their effects on the environment. Furthermore, showing that fly ash and jarosite can successfully be reused could lead to the initiation of more studies in their reuse especially in countries where a lower percentage of these wastes are being reused.

2. Characteristics of fly ash and jarosite

For decades many researchers have carried out studies on jarosite and fly ash. This section provides some characteristics of fly ash and jarosite. It should be noted that there are two grade of fly ash namely Grade F (contains SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ > 70%) and grade C (contains SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ > 50%). Furthermore, the Grade F is principally generated from the combustion of anthracite or soft coal with Calcium Oxide (CaO) while Grade C is produced from the combustion of lignite or sub-bituminous coal with Calcium Oxide (CaO) [25].

The measured densities of jarosite and fly ash were carried out in [7] and were 3.1 g/cm$^3$ and 2.21 g/cm$^3$. It can be seen that the density of jarosite is higher than that of the fly ash. The morphology of jarosite shows irregular grains shape and non-uniformity in structure while the fly ash displays regular, cenospheric and spherical structures. Figure 1 (a) and (b) depicts the surface morphology of the fly ash and jarosite [2] respectively. The main chemical composition in fly ash is SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, CaO, MgO, K$_2$O and Na$_2$O [23]. Other researchers obtained similar main chemical elements with some additions such as TiO$_2$ [8]. On the other hand, the main chemical composition in jarosite are were CaO, Al$_2$O$_3$, SiO$_2$, Fe$_2$O$_3$, MgO, K$_2$O, Na$_2$O, SO$_3$ and TiO$_2$ [14].

Furthermore, the Toxicity Characteristic Leaching Procedure (TCLP) analysis was carried out to ascertain the hazardous nature of the jarosite and toxic elements such as Arsenic, Lead and
Nickel was found [7]. Studies on the phase’s composition of the Jarosite and fly ash can be found in [7, 23]. Figure 2 shows the X-ray diffraction (XRD) phase composition of jarosite and fly ash [7, 23].

![Figure 2: Showing the X-ray diffraction of (a) fly ash [7] and (b) jarosite [23].](image)

In [7], the XRD showed the presence of Quartz (SiO₂), Mullite (Al₄.₆₄Si₁.₃₆O₉.₆₈), and Calcium Oxide Silicate Chloride (Ca₂O₂Si₃Cl₂) as the major phases. On the other hand, the phases obtained in the jarosite [23] were, jarosite (K (Fe₃(SO₄)₂(OH)₆)), Iron Sulphate Hydrate (2Fe₂O₃SO₃5H₂O), Ammonium Iron Sulphate Hydroxide (NH₄Fe₃(SO₄)₂(OH)₆) and Lead Sulphate (PbSO₄).

3. Utilization of fly ash and jarosite in construction

To mitigate the impact of produced solid wastes such as jarosite and fly ash, their reuse in various products should be investigated. This section presents summaries of selected studies in which jarosite and fly ash are used in various construction materials such as bricks, concretes and as aggregates.

3.1. Bricks making

In the construction industry bricks are one of the most used products and researchers have carried out studies on the usage of jarosite and fly ash as constituents in bricks. Esmeray and Atıs [6], used sewage sludge, fly ash and oven slag wastes to make clay bricks. They used two firing temperature (900 °C and 1050 °C ) and indicated that the compressive strength was reduced when the wastes materials were used and that the usage of different wastes materials did not positively affect the properties of the bricks. In another study [7], jarosite/clay/fly ash admixtures were used to make bricks fired at 900 °C. They stated that the compressive strength of some admixtures ratios (1:1 and 2:1) using 15% and 20% fly ash, 40% and 42.5% jarosite yielded satisfactory compressive strength results. And those obtained results met the minimum required engineering property standard in the construction industry [7]. In [7], the leachability of the admixtures using Toxicity Characteristic Leaching Procedure (TCLP) was
investigated. The samples heated at 900°C displayed that toxic elements including Lead (Pb), Iron (Fe) and Nickel (Ni) were neutralized, however, Arsenic (As) concentration was above South African recommended TCLP limits. They, therefore, concluded that the bricks can be used for internal walls [7]. Figure 3 (a) shows the bricks made using sewage sludge/fly ash /oven slag [6], (b) bricks made using jarosite/clay/fly ash [7] and (c) the compressive strengths of different ratios compared to the industrial standard [7]. This shows that if the right mixtures are used, jarosite and fly ash wastes can be used to make bricks with acceptable compressive strength values and meet the standards. Furthermore, more studies are needed to investigate the effective usage of jarosite and fly ash in combination with either other wastes or materials to make bricks with satisfactory properties include compressive strength.

3.2. Concrete making and as aggregates

Concretes and aggregates are used in many structures in the construction industry. Many studies have been carried out and this section presents the summaries of few studies to show that jarosite and fly ash wastes can be used in concrete and as aggregates with a focus on the strengths. The fly ash was used as sand replacement and the concretes were cured using
different times [4]. The compressive strength of 7 and 28 days curing for the paver blocks comprising fly ash (up to 30%) exhibited higher values compared to the strength of the paver blocks without fly ash. Furthermore, the maximum compressive strength for all the profiles was obtained at 10% replacement of cement with the fly ash [4]. They also said that the optimal fly ash percentage is 30%.

Figure 4. depicts the compressive strength of concrete in which jarosite and fly ash at different percentages are used as constituents. It also shows the fabricated concretes, cast paver blocks and tiles.

Figure 4: (a 1 and 2) showing cast paver blocks (a1), cast tiles (a2) with fly ash [4], concrete made with jarosite as a component exposed to normal curing, H2SO4, NaCl and MgSO4 [15], (c) showing compressive strength values of concrete made with fly ash as a constituent using various curing time [13], (d) compressive strength values of concretes made with jarosite as a constituent using different curing time [15].

But when the jarosite is used in concrete [15], high compressive strength was attained when the curing days are augmented from 3 to 28 days. A compressive strength value of 19.4 MPa was obtained after 3 days curing time and after 28 days the compressive strength increased by 57.1%. They further observed that when jarosite percentage is increased, the compressive strength decreased slightly. Kamal and Mishra [19] developed a new fly ash aggregate (FAA) which was lightweight, compared it to the traditional gravel aggregate and the low density
round shape aggregates. They stated that the fly ash aggregates is a good alternative for natural aggregates and can be a solution to waste management (ecologically sustainable) [19]. In [21], jarosite has been used as aggregate replacement in cement concrete and the compressive strength was higher when higher replacement levels at all the ratios. They further said that, when the percentage of jarosite is increased, it fills properly the pores which resulted in developing a dense particle packing.

It is noteworthy that other properties of construction materials such as water absorption, specific density, and flexural strength have been also affected by the use of jarosite and fly ash. Furthermore, it was observed that the reuse of jarosite and fly ash are used as constituents, the compressive strength is affected positively if the right amount of waste is used.

Conclusions

The impact of wastes worldwide has shown to be detrimental to the environment and the reuse of these wastes could alleviate their negative impact. Jarosite and fly ash are solid wastes and have been used in many products including construction materials. Jarosite and fly ash have been used in bricks and concretes and it was established that the obtained compressive strength is up to standard when the right ratios are used. Based on the successful reuse of jarosite and fly in the construction industry, it of importance that more economical and environmental studies be carried out to investigate the safe usage of these wastes and their cost-effectiveness. This could lead to an increase in the usage of the above-mentioned wastes and other wastes to reduce their damaging impact.

Acknowledgement

The authors will like to appreciate partial support of Covenant University toward publication of this work

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