Material Characterization of Blast Furnace Slag and Fly Ash of Bhilai Steel Plant for Value Added Replacements in Building Construction Materials

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Abstract

Waste management deals with the management of materials that are considered as materials with apparently no value however it is not useless material it is just used less material; it is the dual responsibility of academia to bridge the existing gap between research and on-field practices. The present research includes the study of material characterization physical, mineralogical, and chemical of blast furnace slag the industrial by-products of steel plants, and fly ash from the standpoint of a material to be used as a partial replacement of sand and cement. The scarcity of sand in various cities of India is being reported and their suitable replacement is essential from a sustainability point of view. Production of ordinary Portland Cement is the seventh largest contributor of carbon dioxide gas emissions into the atmosphere. Considering the above factors using these by-products in the production of concrete which is produced by using locally available material is a tested and proven solution. But, only a limited attempt to explore possibilities of using these byproducts from BSP is made to date. The innovation in the present study is the dual replacement of sand and cement in producing concrete using industrial byproducts. It is worth mentioning here that concrete is the world's most used material only next to water, the byproducts yield satisfactory results in the various essential parameters of concrete like workability, strength, and durability offer a multifold benefit to society and stakeholders of steel and construction industry. Reduction in age-old dumped waste and gainful utilization and recycling of these wastes by converting them to value-added wealth in one form or another will not only improve the economics of operation but also prevent degradation of the ambient environment.

1. Introduction

One aspect of waste management is handling materials that appear to be worthless. But if the composition is not precisely determined, the "Environmental saving" that can be realized by employing rejects could be lost. As a result, before wastes can be managed, they need to be thoroughly recognized through physical, mineralogical, and chemical investigation.

It becomes increasingly important to make use of the waste materials that are continuously and massively created by converting work materials into by-products or in-process materials for recycling as circumstances change, time goes on, and technology advances.

1.1 Steel Industry Scenario

Steel is an iron alloy with trace elements of carbon, manganese, chromium, nickel, molybdenum, zirconium, vanadium, and tungsten. Currently, catalogs list over 3000 different steel grades. In 2007, the world produced 109.3 MT of steel, an increase of 7.6% over 2006. China, Japan, and the United States are the top three producers of steel, generating a total of around 100 million tonnes annually.

The major steel producers in India are SAIL, TISCO, RNIL, Essar, Ispat Alloy, Jindal Lloyds, and Usha Group. The seven integrated steel plants are Tata Steel Company, Bhilai Steel Plant (BSP), Bokaro Steel Plant (BSL), Durgapur Steel Plant (DSP), Indian Iron &Steel Company (IISCO), Vishakhapatnam Steel Plant (VSP), and Rourkela Steel Plant (RSP). The primary product of SAIL is steel, while it also produces ferroalloys, chemicals from coal, tar products, light oil, and fertilizers. Through a network of stockyards and distribution centers across the country, the company sells its goods.

The Bhilai Steel Factory is one of the first three integrated steel mills that the Indian government developed to create a strong basis for the development of the nation's industrial sector. It serves as a symbol of Indo-Soviet techno-economic cooperation. The Bhilai Steel factory houses a number of processing facilities, such as (A) an ore bedding and bending facility, (B) coke ovens, (C) sinter plants I, II, and III, and (D) blast furnaces 1, 2, 3, 4, 5, 6, and 7. Plate mills (G), Hot Strip Mills (H), Silicon Steel Mills I & II (F), Cold Rolling Mills I & II (E), etc. It produces a variety of high-end steel products, including Tin plates, CRNO Coils/Sheets, GP/GC Sheets, HR Plates and Chequered Plates/Sheets, ERW pipes, and SW pipes. In addition to two oxygen plants, engineering shops, machine shops, and various other supporting organizations, Bhilai has two captive plants with a combined generating capacity of 110MW. The 74MW power plant II has been purchased by a joint venture firm owned equally by SAIL and NTPC.

Many different processes are used to make steel. A blast furnace creates heated metal, which is then converted into steel and rolled into a final product, starting with naturally occurring raw materials like coal and iron ores. Other activities are also carried out inside the steel mill to varying degrees, such as the production of refractory material. A lot of garbage is created by those actions. Depending on the methods used to make the steel and the pollution control measures put in place, different types of waste are produced in different quantities at the steel plants.

For easy understanding, the steel plant solid waste has been broadly classified into categories:

(a) Solid waste generated from process units.

(b) Solid waste generated from pollution control equipment.

The quality of the raw materials utilized and the technology employed are the main determinants of the volume of solid waste generated by processing units. Process unit solid wastes are usually identified by their homogenous size and composition, low moisture content, and high concentrations of Fe, Ca, C, etc., making them suitable for recycling inside the plant or for sale to consuming industries. The amount of solid waste generated by pollution control equipment is primarily influenced by the type of efficiency—dry or wet—and the quality of its feed materials. Various sizes and types of dust and sludge are produced by flue gas and pollution control equipment.

1.2 Need for waste classification, characterization, & utilization

Waste is something that is unwanted or unusable. Nevertheless, what is unwanted in one situation might be beneficial in another, and what is useless in one industry might be profitable in another. To profitably use what may otherwise be regarded as waste, it is up to the human imagination to develop solutions, establish new markets, and develop cutting-edge technologies. Byproducts are an inevitable result of any mining and industrial activities. A steel factory's handling of the many solid waste types is a difficult task. Even if the basic plan is to look into the possibility of recycling, enrichment, and additional treatment within the production system, it is usually challenging to include them in a flow chart for an established process. These solid wastes frequently have salvageable and recyclable useful components.

1.3 Problem definition

The Bhilai Steel Factory faces a challenge with solid waste management because it produces more garbage than all other facilities in India and abroad put together. Although most solid waste is in the form of slag (Blast Furnace Slag, Steel Melting Slag), dusts (Flue Dust, SMS Dust), sludge (GCP Sludge from Gas Cleaning Plant of Blast Furnace, Acetylene Sludge from Acetylene Plant, Neutralization Plant Sludge and Palm Oil Sludge from Cold Rolling Mill, Acid Treatment Plant Sludge from Sillcon Steel Mill), scale, and other materials, there The majority of solid waste output, or around 90.48% of total generation, is made up of waste from steelmaking (14.84%), captive power plants (1.30%), and waste from ironmaking (74.34%)Preliminary research on the recovery of valuables from specific waste, such as flu dust and fly ash, has been conducted using a variety of physical beneficiation processes based on the results of the characterization. Only a few attempts have been made to determine alternative methods of further using some of these wastes produced by the Bhilai Steel Plant.

1.4 Scope of present Investigation

The current research is fundamental and useful. In an integrated steel factory like Bhilai Steel Plant (BSP), multiple raw materials and processed products are employed in a range of manufacturing processes. The Chhattisgarh Bhilai Steel Plant's waste materials will be **characterized** in terms of their physical, mineralogical, and geochemical characteristics. The investigation will also look into possible ways to best **utilize** some of these waste products for some **value-added** applications.

Due to these objectives, the work plan for this research programme has been split into two parts, including the characterization and use of the solid waste generated at BSP. Before discussing their qualities, the various wastes' origins and processing technologies are briefly described.

1.4.1 Characterization

- Mineralogical and geochemical characterization of waste material generated from metallurgical furnaces (Iron Making & Steel Making).
- Mineralogical and geo-chemical characterization of waste material generated from Bhilai Steel plant.

1.4.2 Utilization

The results of the above investigation have been synthesized to find out the amenability of the waste materials to upgrade and further utilization.

2. Materials and Methods

2.1.1 Material Details

This research project's main goal is to look into BSP solid waste. The different plant rejects include steelmaking-LD slag, flu dust, and (A) metallurgical furnace waste. (B) Thermal power plant fly- and bottom-ash waste. The physical, mineralogical, and chemical features of these samples have been characterized, and efforts have been made to extract any prospective value-added products from any of them.

2.1.2 Iron making Furnace (Blast Furnace)

Iron ore, limestone, and coal are the three main basic materials utilized in the BSP's blast furnace to create hot metal (pig iron). Hematite (Fe2O3), the iron ore, is converted into Fe-metal during the smelting process, and all impurities are released as slag. The significant amount of slag produced by the blast furnace is a result of the high ash content of the metallurgical coal used at BSP and the high alumina contribution of the iron ores. Thus, it is necessary to reduce the coke rate in order to increase output and hot metal quality. High flux sinters containing MgO are created to do this. At BSP, there are two sinter plants. During sintering, the fuel contained in the charge is agglomerated with the iron ore fines, dolomite, and limestone. The resulting porous, lumpy material is known as sinter.

In the blast furnace (BF), the reduction of iron oxide results in the development of several byproducts. These are gas cleaning sludge, flue dust and blast furnace slag

Table .1: Input & output data of Blast Furnace for production of1Toneof Hot Metal

Input		**Output**	
Iron ore	985kgs	Hot Metal	1000kgs
Sinter	800kgs	Slag	435kgs
Mn-ore	35kgs	Flue Dust	25kgs
Limestone	08kgs	BF Gas	1830kg
Converter slag	32kgs		
Coke	596kgs		
Compressed air	25M3		
Electricity	33.7kwh		
Air blast	2600M3		
Water	40M3		
Steam	120kgs		

2.1.3 BF Dust (Flue Dust)

Generation Process of Flue Dust

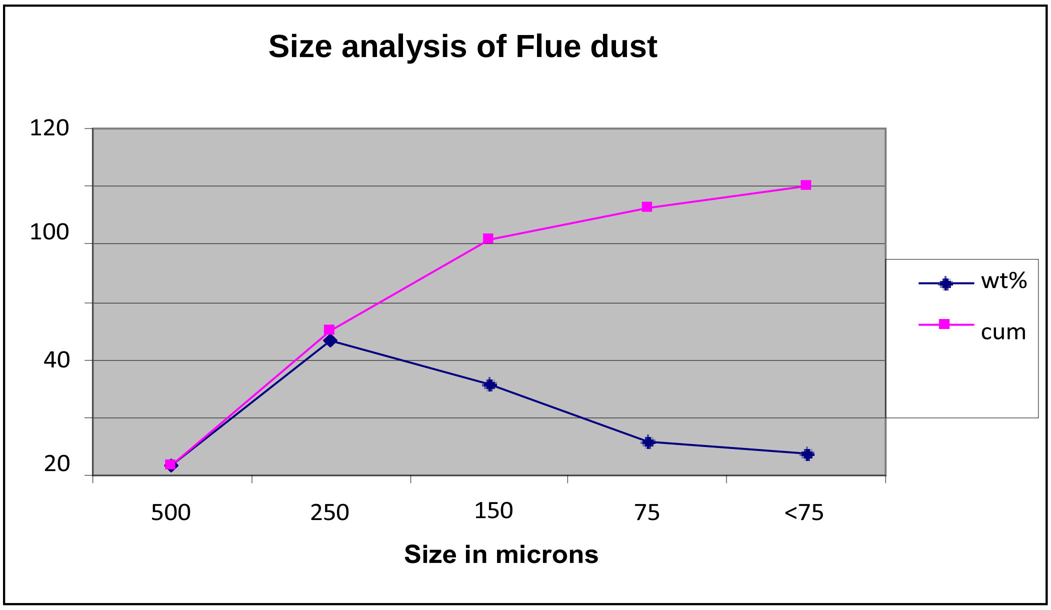
Flue Dust, along with Hot Metal and slag, is the third gaseous product to leave the top of the furnace. A little amount of charged dust is present in this gas. Some of these particles can be separated with ease using a dust collector, while others can be precipitated as sludge (Fig. III.3).

3. Characteristics of Flue Dust

3.1. Physical Characteristics

Hands are stained by fine-grained, black flue dust or blast furnace dust. The flue dust appears dark because of the abundance of unburned coke particles. They are mostly asymmetrical in shape, with a few extremely uncommon euhedral grains. Granular density of a sample of flue dust is 2.78.

Size micron	Weight gms	Wt%	Cumulative
500	24	3.11	3.11
250	360	46.75	49.86
150	242	31.42	81.28
75	88	11.45	92.73
<75	56	7.27	100

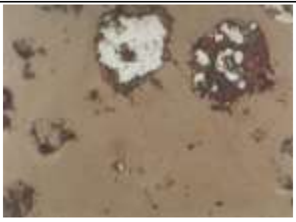


Graph 1 : Size analysis of Flue Dust

3.2. Optical Micrographs of Flue dust

Grain feed, partially reacted: - Unreacted or partially reacted ore-oxide particles make up a significant portion of the dust Some of them have a spherical crust that formed as a result of their exposure to extreme heat. They come in a variety of sizes and shapes (angular, irregular). (See Fig.).

NO		

1.		White grains of Haemetite
2.		Magnetite with unaffected Hematite grain
3.		An un burnt coke grain showing leafy structure
4.		Unaffected Hematite grain with limonite incrustation

3.3 Chemical characteristics

It contains a lot of fixed carbon (31.0%), a lot of iron (42.6%), and only a little bit of silica (SiO2-5.7%), alumina (Al2O3-10.40%), and calcium (CaO-2.00%). It loses fixed carbon content as it grows in size (+1,250 microns, 31%, +150 microns, 24%, +75 microns, 8.5%, +75 microns, 4.5%). The permitted limits for the environmentally hazardous elements Pb, Zn, Cu, Cr, Mn, Ni, Th, and U are greatly exceeded.

Table 2: Major, Minor & Trace element Distribution pattern in BF dust.

Major Elements	**Wt%**
Carbon	4.31
Fe_2O_3	42.6
SiO2	5.7
Al_2O_3	10.40
CaO	2.00
MgO	1.6
MnO	0.57

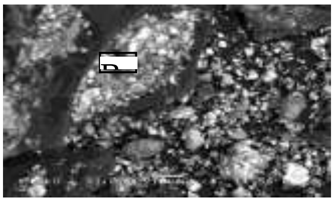
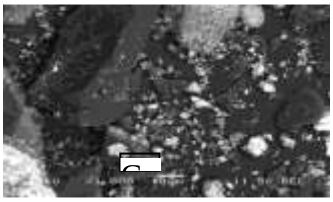
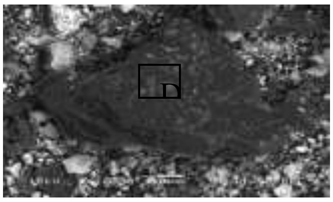
Trace Elements	**(in ppm)**
Pb	25.12

Zn	42.52
Cu	29.60
Cr	0.50
Ni	18.22
Th	43

3.4. SEM Analysis of Flue dust

Electron microscopy relies on the scattering of electron beam sweeps over the material to form images as opposed to optical microscopy, which uses light as the image-generating source. This research, in general, exposes the size, shape, and micro morphology of minerals as well as their textural patterns. Results of the SEM analysis of flue dust are displayed in the Table:3

Table 3 : SEM analysis of flue dust

NO	SPECIMEN	**Element**	**Wt%**
1.	A grain of iron carbide containing small Amount of calcium. 	Fe C Al Si	48.41 43.16 2.30 1.39
2.	High iron bearing carbon particle. 	Fe C Al Si	39.83 57.19 0.73 1.26
3.	A carbon particle (un-burnt coke) In flue dust. 	C Al Si Fe	97.24 0.70 1.19 0.51

4. Characteristics of SMS Slag

4.1.1 Physical characteristics

The nature, density and porosity of SMS slag is given inTable4.5. LD slag appears grayish black and less porous.

Table 3 : Physical properties of SMS slag

Type	Nature	Bulk density	Porosity

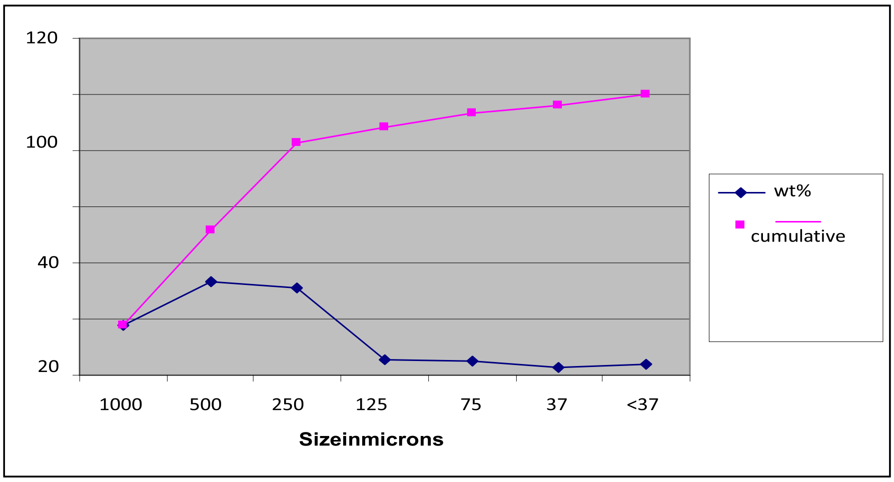
LD slag	Hard, massive and compact	3.645	0.009
LD slag	Porous	3.373	0.026

Table 4: Physical properties of SMS slag

Type	Wt of dry sample (W_1)	Wt of sample in water immersion (W_2)	Bulk density
Flat	4.07	3.57	8.12
Irregular	4.69	3.93	6.13

Table 5: Size analysis of LD slag

Size in micron	Wt	Percent wt	Cumulative
1000	68.99	17.84	17.84
500	129.84	33.59	51.43
250	120.19	31.09	82.52
125	21.46	5.55	88.07
75	20.02	5.18	93.25
37	11.02	2.85	96.10
<37	15.00	3.88	99.98



Graph 2 : Size analysis graph of LD slag

4.1.2 Optical micrographs of LD slag

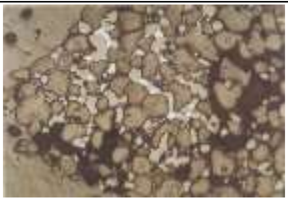
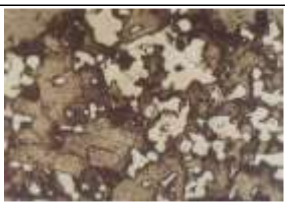
The crystalline textures vary from dumbbell shaped crystal to circum form skeletal crystals. Microscopic characteristics of dominant phases are discussed below.

4.1.2. a) Metallic Fe-phase:-

Fine globules of metallic Fe-particles are extremely rare and typically appear in enormous sizes (>125 micron) (Fig. IV.12C). They either had thick or thin glassy incrustation or were made up of a single metallic phase (Fig.E & C). On rare occasions, they show a glassy phase-enclosing flow structure (Fig. IVD).

4.1.2. b) Iron-rich phase:-

The secondary Wustite phases make up the majority of the iron-rich phases (Table 4) which have an erratic form. A typical characteristic of wustite is that it partially oxidises to hematite along the octahedral planes. Although Ca-rich phases are prevalent in LD slag, as shown by SEM analysis, they were not seen using optical microscopy.

Fig A		Large iron metal grain showing irregular boundary.
Fig B:		Dumbell shaped iron metal-small grains of wustite.
Fig C		Cluster of circular slag particles with small wustite and metallic prills occupying the inter granular face of slag. X 100
Fig D:		Irregular shaped wustite grain associated with slag grains.X100.
Fig E:		Ovoidal grain of slag occurring in association with wustite grains. X100.
Fig F		Fine inclusion of slag grain within wustite.X100.

4.1.3 Chemical characteristics

When compared to THF slag, LD slag exhibits a lower incidence and a higher calcia content in terms of composition. The LD salg sample was ground into a variety of size fractions, including 1000 microns, 500 microns, 250 microns, 125 microns, 75 microns, 37 microns, and 37 microns, to learn how the elements were distributed and to examine the sintering properties. All size fractions show a about identical amount of distribution (Table).

Table 5: Major & minor element distribution in various size fractions of LD Slag

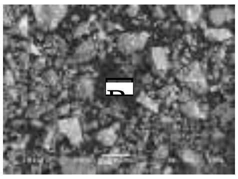
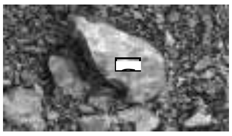
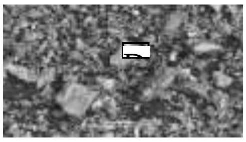
Size(μ)	**FeO**	**SiO2**	**CaO**	**MgO**	**MnO**	**Al_2O_3**	**TiO_2**	**P_2O_5**	**S**
1000	26.50	12.99	45.35	6.95	3.66	1.60	0.84	1.80	0.13

500	26.58	13.90	43.51	8.34	3.67	1.50	0.80	1.69	0.12
250	25.23	14.43	44.18	9.31	3.49	1.47	0.79	1.78	0.11
125	25.28	14.06	42.49	9.33	3.46	1.67	0.79	1.69	0.12
75	26.77	14.00	40.17	8.73	3.52	1.79	0.76	1.67	0.12
37	24.45	15.75	41.06	9.94	3.27	2.01	0.77	1.73	0.12
<37	26.29	15.35	39.33	9.04	3.47	2.09	0.78	1.70	0.12

Trace elements (inppm)	
Zn	7.05
Cr	460.16
Co	2.50
Zr	439.77
U	1.02
Th	10.04
Ta	33.51
V	13.33
Y	10.04
Pb	2.97

4.1.4 SEM Analysis of LD slag

This investigation reveals the size, form, and micro morphology of minerals as well as their textural patterns. Table (A-D) provides the SEM study of flue dust

A.		SEM photograph of LD slag using SEI technique**.**
B.		Calcium silicate crystal. Ca= 81% Si- 18%, Probablephase:$CaSiO_2$
C.		Di-calcium (Mg,Si,P) ferrite Ca= 59.82% Fe- 25.57%, Ph= 2.129%, Mg = 1.79%,
D.		Calcium magnesium ferrite with silica. Ca= 31.49%, Mg = 13%, Fe= 51%, Si= 4.5%, Probable Phase CaMg Si Ferrite

5. UTILIZATIONOF WASTE

5.1 Present Status and Future Prospects

In an integrated steel plant, around 3.5 tonnes of solid wastes like slag, dusts, sludge, fly ash, etc. are produced for every tonne of finished steel produced, whereas approximately 5 tonnes of input materials like iron ore, coal, fluxes, Mn ore, ferro alloys, etc. are needed. These wastes are exceedingly expensive to collect, move, and dump, thus a lot of land must be set aside for them. An indication of the efficiency or inefficiency of a steel plant's functioning is the amount of waste it produces. Reducing the amount of waste produced, as well as using it productively and recycling it, not only boosts the steel plant's operational efficiency economically, but also preserves the ecosystem and preserves the peace of the area around it.

The three significant solid wastes, BF slag, SMS slag, and fly ash, together make up around 94% of the entire waste produced at BSP. The sizing and screening procedure for diverse raw materials results in smaller amounts of undersized raw materials. Normally, sintering processes are used to recycle flu dust. Because they contain less than 1.7% of alkalies, BSP recycles about 50% of the whole amount of Flu dust produced. Flu dust has a significant iron concentration and about 30% unburned carbon.

The BSP sample however does not contain any significant amount of Pb and Zn as reported in flue dust samples from other parts of the world . The concentrations of environmentally hazardous heavy metals such as Ni, Cu, and Cd etc. are also low. The 50% passing size of the sample is found to be ≈250µm. The carbon values are mostly concentrated in the coarser fraction while the iron values in the finer fraction.

5.1.a. Utilization of Flyash

Utilization of Fly ash as a building material can largely attempted in Building industry, a fast-growing sector and is one of the key areas of infrastructure development. At present the building industries depend on the use of natural resources to fulfill the demand of construction materials in the country. Naturally occurring stone aggregates, gravel and sand are very popular for their use in building and road construction. Utilization of these materials is gradually restricted to save the destruction of landscape and valuable forest- lands and to check their impact on environmental degradation. Search for alternate material and utilization of various industrial solid wastes in construction industry is considered to be very important. Fly ash being a powdery material, its use in various building construction activities is limited. Conversion of powdery fly ash into lumpy aggregates is one of the methods for bulk use in various constructional activities. As early as 1957 and 1963 the use of fly ash in form of sintered light weight aggregate pellets as construction material was initiated in UK and USA respectively. Since then, the manufacture of sintered light weight pellet from fly ash and its utilization in mass concrete, construction for acoustic and thermal insulating building materials in seismic zones and arctic climates, masonry bricks and blocks, road and embankment have made significant progress. Many developmental activities have been carried out in commercial production of sintered light weight pellet for building material use from flyash and other solid waste such as Fe-dust, LD dust, acetylene sludge, mineral fines etc. by adopting rotary kiln and continuous sintering system is well known in iron and steel industries for agglomeration **of** iron ore fines for blast furnaces.

During the combustion process used to produce energy, captive thermal power plants (CCP I & II) in BSP produce a significant amount of ash (fly-ash and bottom-ash). Fly ash is frequently used in a variety of applications, including the production of bricks, pozzolanic materials for cement, artificial aggregates, mine stowing materials, etc. Brick manufacture can utilize BSP fly-ash as well as acetylene plant sludge, neutralization plant sludge, and neutralization plant sludge. It is possible to successfully separate the iron-rich fly-ash phases using wet magnetic separation and then recycle them into blast furnaces using sinter plants.

5.1.b. Utilization of Slag

Slag from the production of iron and steel makes up the majority of the solid waste at Bhilai Steel Plant. Indian coals have a high ash percentage, which causes a lot of slag to be produced in the blast furnace and causes environmental issues when it is disposed of. Portlandite, Wustite, hematite, and rankite minerals are present in the hard, dense slag produced by Steel Melting Shop II. This slag has a strong basicity, or an excellent calcium to magnesium ratio, which can neutralize the siliceous or acidic components of gangue in blast furnace load. However, the large-scale use of it is restricted by its high P2O5 content.

LD slag can be used to make cement after treatment, and iron can be extracted from it. Granulated LD slag can be used to improve soil. It is possible to create a proportionate increase in soil pH by adding LD slag to the soil. This enhances the quality of the soil and its productivity too.

A new door has been opened for their potential for use as a result of the thorough mineralogical and geochemical analyses done on the solid waste of the Bhilai steel mill by utilizing trash in an environmentally sustainable way.

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