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Feasibility Study on Application of Blast Furnace Slag in Pavement Concrete

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Abstract: Concrete is the most-used man-made product in the world. Concrete is widely used for making many types of structural components for different civil engineering applications. In this modern era, cement concrete pavements are in demand as compared to bituminous pavements in highway projects. Due to limitation of quality natural resources for making concrete, the waste utilization in production of concrete especially for pavements are major concern in advances of civil engineering. Blast furnace slag is one of the wastes produced from steel processing plants around the globe. Rajkot (Gujarat) is well known for its small scale industries for long time and one of the fastest developing cities of India is hub of steel and allied industries. Rajkot itself produces blast furnace slag of amount 2500T/month from its 2000 steel processing units. This enormous quantity of blast furnace slag is generally dumped in unscientific manner create environmental issues and little is used for landfill purpose without any technical input. It is interesting to know whether Blast Furnace Slag (BFS) can be utilized as a fine aggregates (i.e. as a sand) to produce concrete mainly for pavements or not. In this paper, the comprehensive experimental programme is taken up to study the feasibility of this BFS used as a fine aggregate in pavement concrete. In this regard the chemical and physical properties of the BFS are observed in this study. These properties depend upon the raw materials used and methods of processing at plants. Based on results of experimentation, variations in chemical and physical properties are studied and checked the suitability of utilizing this BFS for pavement concrete. The results indicate that BFS can be utilized as a fine aggregate in pavement concrete.

Keywords: Blast furnace slag, Concrete, Sand, Pavement, Waste materials

I. INTRODUCTION

Concrete is an important and successful material in the construction industry for a long time. It has so many applications and utilization in the construction field also includes the pavement construction. Due to advancement in technology and constantly increasing economy, construction industry develops in everlasting leaps and bound day by day. This boom in construction, demands massive amount of concrete to be produce to satisfy the current need. This enormous quantity of concrete requires a deal of quality raw material which produce concrete. The raw materials of concrete mainly natural products like aggregates and sand except cement. As it is the second largest consumed material by human kind, the natural raw material which produced concrete is day by day become scare. There is acute need of work out some other source and type of material which can be utilized for production of concrete with same outputs. Concrete is vary complex and heterogeneous material. This creat a technological challege among the technocrate to work out certain materials which fulfil this task. In the era of advances in technology, one of the concept is to use waste materials in the production of concrete. Out of many waste materials available, Blast furnace slag is one of them. Blast furnace slags are by-products of metallurgical processes. Steel- and iron making industries generate different types of slag. Blast furnace slag, which is a by-product of iron making process, has a high SiO₂ content and hence rapidly cooled blast-furnace slag, has an amorphous structure and pozzolanic properties. According to Indian minerals yearbook 2011, blast furnace slag generation was estimated about 10 million tonnes range in the India and approximately 15 to 40% of the total slag was utilized. Traditionally unutilized slag is stock piled in the steel plants, and eventually land filled at slag disposal sites. Since the current methods of stockpiling and land filling are not sustainable, disposal of slag has become a significant concern both to slag processor companies and to environmental agencies in the last decades. Sustainability of blast furnace slag in civil engineering applications especially in road construction will not only alleviate the blast furnace slag disposal problem but also will offer a cost-effective substitute

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

for conventional materials. In order to identify new applications for blast furnace slag in the construction industry, there is a significant need to characterize blast furnace slag, and to determine their engineering properties. There is very limited information on the engineering properties of blast furnace slag in the literature. Research that focuses on engineering properties of blast furnace slag is scarce. Therefore, in comparison to other recyclable materials, such as flyash, bottom-ash, tire shreds, cement kiln dust or foundry sand, blast furnace slag is underutilized.

Rajkot is the fourth largest city of Gujarat state and well known for its small scale industry. In the saurashtra region i.e. the western part of Gujarat state, Rajkot is famous for its heritage and particular geographic location. Currently, Rajkot is considering well developed city through its infrastructure reforms. As it is mentioned Rajkot is hub of small scale industry, the most of the manufacturing works are related to the steel, alloys, metals etc. This accounts the enormous quantity of blast furnace slag production within the Rajkot itself. The estimated no. of units related to the steel, alloys, metals etc. are 2000 nos. and due to different manufacturing processes the estimated amount of blast furnace slag production is 2500 tons/month. This enormous quantity of slag at present either dump in unauthenticated manner or a very small quantity of it can be utilized for some earth fill work but that also in unscientific way. In this paper, a comprehensive experimental program is undertaken to evaluate the feasibility of utilizing blast furnace slag as materials. To ascertain the potential use of this BFS as fine aggregate in pavement concrete, chemical and physical properties need to be evaluating by performing various test on BFS. Samples are collected from different location in optimum nos. to carry out the test. Experimentation is shown promising results of different parameters related to the BFS. This result provides variation in the different chemical and physical properties of the BFS which is at par with various international guidelines available in literature. This paper provide the platform and information for utilizing the BFS as fine aggregates in pavement concrete as well as guidelines for properties of BFS for other sources just like Rajkot(Gujarat) with respect to raw materials and processing methods used.

II. REVIEW OF LITERATURE

Introduction

Many researcher and technocrats were put their sincere and elaborate efforts to use the slag coming out from steel processing units in different civil engineering application. Many of them are not pertaining to pavement concrete as Blast Furnace Slag (BFS) is also utilized for other civil work applications like earthfill, embankment, sub-base and base course for pavement etc. Provisions in International codes for related topic are reviewed as no such provisions are available in Indian context. Following paragraph illustrate the initial development in the utilization of this slag as well as latest scenario for different civil engineering application.

BFS is obtained during the manufacture of iron and steel, and possesses inherent hydrated properties. It can be utilized for making different types of construction materials[19]. According to Emery (1980), loose dry unit weight values for palletized BFS range from 8.2 to 10.4 kN/m³. Blast furnace slag is a glassy material, typically with sand-to-gravel-size particles[1]. Research that focuses on engineering properties of BFS is scarce. There is very limited information on the engineering properties of blast furnace slag in the literature. Noureldin and Mc Daniel (1990) and Lee (1974) reported on some of the engineering properties of blast furnace slag[2].

Skid resistance is a measure of the minimum force at which a tire prevented from rotation and slides on the pavement surface. Development of sufficient skid resistance is an important requirement of road safety. In this regard, BFS is a favourable aggregate for bound asphalt applications as BFS aggregates are angular and have a very rough surface texture. Therefore, pavement surfaces incorporating BFS have shown superior skid characteristics than asphalt surfaces incorporating natural aggregates[4]. Two recent studies by Shen et al. (2009), and Ahmedzade and Sengoz (2009) proposed the use of BFS as coarse aggregate in asphalt mixes[5]. BFS were used as sub-base materials for pavement construction and promising results were found[6]. The effects of fluctuating temperatures on the setting times of concrete mixtures made with supplementary materials like flyash and BFS were studied[7]. Many researchers have studied, the effect of powder form of BFS as a replacement of cement for mortar and workout the rate of hydration and setting time[8,10,12]. Thermal properties of PCC pavement containing the different proportion of fly ash and BFS were studied the critical temperature gradient through the slab thickness[9]. In most of the research work, the combination of different waste materials like BFS, flyash, steel slag etc. were taken to know the different properties[10,12].

The paper Submitted in the 92nd Annual Meeting of the Transportation Research Board describes sustainability aspects of using ACBFS as a coarse aggregate in concrete pavements and considerations for its use in this application are presented. Chemical composition of ACBFS may affect its performance and has to be considered when using it as a coarse aggregate. Physical properties of ACBFS such as texture, absorption, and specific gravity also have to be

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

considered when using ACBFS in concrete. ACBFS also affects fresh and hardened properties of concrete. There are specific design, construction, and quality control considerations that have to be taken into account when using ACBFS[13]

Central Road Research Institute (CRRI) is the primary and well known organisation in India describes the utilization of industrial wastes and by-products in concrete road construction as a one of the research area. Project sponsored by different agencies related to utilization of Lead Zinc slag, fly ash, marble slurry etc. are undertaken by scientists at Rigid Pavement Division of CRRI[21].

Apart from above information, utilization of blast furnace slag in India is very limited in comparison with abroad. Eventually, guidelines for utilization of this slag are not available in any BIS codes, IRC publication or any other reputed organization’s publication in context with this topic[18]. This ultimately leads the researcher to take the help of some international guidelines and publications.

International Standards for Use of Air-Cooled Blast Furnace Slag in Concrete

Currently there is no ASTM international standard that specifically addresses the use of ACBFS as an aggregate in concrete. Several countries have previously had separate standards for ACBFS aggregate, but more recently have integrated the information on ACBFS into their standards for concrete aggregates, as summarized in the following sections

Japanese Standards

- The Japanese Industrial Standard JIS A 5011-1977, Air-Cooled Iron Blast Furnace Slag Aggregate for Concrete (JIS 1977), and newer Japanese Standard JIS A 5011-1:2003—Slag Aggregate for Concrete—Part I: Blast Furnace Slag Aggregate, specified the following properties shown in Table-1 for ACBFS coarse aggregate to be used in concrete^[22]:

Table: 1. Chemical Composition and Physical and Chemical Properties of ACBFS

Item		Blast Furnace Slag Coarse Aggregate	
		Class L	Class N
Chemical composition	Calcium oxide (as CaO) %	45.0 max.	
	Total sulfur (as S) %	2.0 max.	
	Sulfur trioxide (as SO ₃) %	0.5 max.	
	Total iron (as FeO) %	3.0 max.	
Density in oven dry condition	g/cm ³	2.2 min.	2.4 min.
Water absorption	%	6.0 max.	4.0 max.
Bulk density	kg/L	1.25 min.	1.35 min.
Immersion in water		Shall be no phenomena such as cracks, decomposition, muddiness, powdering.	
Irradiation by ultraviolet light (360.0 nm)		Shall be no light emission or uniform purple luminance.	

British/European Standards

- The British Standard BS 1047-1983, Air-Cooled Blast Furnace Slag Aggregate for Use in Construction (BS 1047 1983), which was withdrawn in 2004 have the following requirements for ACBFS aggregate used in concrete^[23]
 1. The bulk density of the aggregate, The stability of the aggregate against iron unsoundness,
 2. The total sulphur content in the aggregate should not be greater than 2 percent, The percentage absorption of the aggregate, The limits of the Flakiness Index of the aggregate, 10 percent fines value of aggregates, gradation.
- A new European standard, CEN EN 12620—Aggregates for Concrete, has now replaced the withdrawn BS 1047 (CEN 2002) have following significance^[26]
 1. Allows ACBFS aggregates to have higher acid-soluble sulphate (up to 1 percent) content and total sulphate content (up to 2 percent), water absorption, volume stability

Australian Standard

- The Australian Standard, AS 2758.1-1998—Aggregate and Rock for Engineering Purposes—Part 1: Concrete Aggregates, addresses requirements for aggregate as follows:^[23]
 1. Water Absorption, L.A. Abrasion Test Values, Iron Unsoundness, Falling or Dusting Unsoundness, Stockpiling of ACBFS Aggregate, Free Lime.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

III. EXPERIMENTAL WORK

Introduction

In the present study, an experimental programme was conducted to evaluate the physical and chemical properties of BFS locally available in major industrial area of Rajkot city. The characterization of BFS is done to check the variation in various physical and chemical properties on selected samples. Major chemical properties like calcium oxide, silica, aluminium oxide, magnesium oxide, sulphur trioxide, and ferrous oxide are evaluated to ascertain its permissible limit which does not harmful for the pavement concrete when BFS is used as a fine aggregates. Experimentation are done for physical properties like specific gravity, water absorption, mass per unit volume, and Iron unsoundness (Immersion test) to find out the suitability of the BFS utilize as fine aggregates for pavement concrete. Details of material used, processing test procedure adopted are described.

Sample Material Used

BSF samples are collected by dividing the area of in and around Rajkot city as per the dumping site of BSF in different industrial zone like, Aji vasahat industrial zone, Samrat industrial area- gondal road, Mandadungar industrial area, Atika etc. 20 nos. of samples are collected from each of this industrial dumping site. During sample collection, some of the samples having porous texture and deteriorate structure are collected separately. Such samples are needed to be omitted as it seems to be failing from physical observation. Such material required screening during collection. Each of these samples is properly identified for experimentation.

Experimental Test Procedure

All the experiments are performing as per the procedure and provision laid down in prevailing national and international codes.

IV. RESULTS

The major aim to perform the experiment on BFS is to evaluate the feasibility of this waste material utilize as a fine aggregate in pavement concrete. The experimental outcome may lead to an extent for utilization of this BFS with respect to same type of raw materials and processing techniques produce elsewhere and same results can be justify based on the results evaluate in parent study. Mainly whole experimental exercise was divided into two parts:

Chemical Properties of BFS:

BFS is more vulnerable for its chemical properties based on raw materials and manufacturing processes. It is important to check the variation in chemical properties before entering into other physical testing on it. As per the sampling done, BFS is tested for its chemical properties with the help of two methods like Chemical Wet Analysis and XRF method. Chemical wet analysis is done by conventional titration method. Analysis by XRF method is done by latest EDX-800 XRF spectrometer machine. As per the methodological technique for chemical analysis, chemical Wet Analysis method is more accurate as compared to XRF method. Results obtained from both the methods are compared and narrated as per different industrial zone and its dumping site within and around Rajkot city in Table-2 to Table -5. Based on the results from various locations, a comparative study of chemical properties of BFS is shown in Figure -1.

Table: 2. Chemical properties of Blast furnace slag (Aji vasahat industrial zone)

Sr. No.	Description	Mini. Value in %		Maxi. Value in %		Avg. value in %		Suggested value as per standards	Remarks
		CWA	XRF	CWA	XRF	CWA	XRF		
1.	CaO	21	25	33	36	28	29	30-43	
2.	SiO ₂	34	35	44	47	40	42	28-42	
3.	Al ₂ O ₃	15	12	25	22	19	16	5-22	
4.	MgO	6	7	7	9	7	8	4-15	
5.	Fe ₂ O ₃	28	30	35	36	32	34	8-10	
6.	SO ₃	0.3	0.3	0.6	0.7	0.4	0.5	1-2	

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

Table: 3. Chemical properties of Blast furnace slag (Samrat industrial zone - gondal road)

Sr. No.	Description	Mini. Value in %		Maxi. Value in %		Avg. value in %		Suggested value as per standards	Remarks
		CWA	XRF	CWA	XRF	CWA	XRF		
1.	CaO	22	24	31	33	26	28	30-43	
2.	SiO ₂	33	36	44	42	35	38	28-42	
3.	Al ₂ O ₃	13	14	18	18	15	16	5-22	
4.	MgO	5	6	7	8	7	7	4-15	
5.	Fe ₂ O ₃	26	27	34	37	31	32	8-10	
6.	SO ₃	0.4	0.3	0.8	0.7	0.6	0.5	1-2	

Table: 4. Chemical properties of Blast furnace slag (Mandadungar industrial zone)

Sr. No.	Description	Mini. Value in %		Maxi. Value in %		Avg. value in %		Suggested value as per standards	Remarks
		CWA	XRF	CWA	XRF	CWA	XRF		
1.	CaO	24	25	36	34	31	30	30-43	
2.	SiO ₂	27	30	40	41	34	36	28-42	
3.	Al ₂ O ₃	12	13	16	16	14	14	5-22	
4.	MgO	6	6	8	9	7	8	4-15	
5.	Fe ₂ O ₃	34	32	44	41	38	37	8-10	
6.	SO ₃	0.2	0.3	0.5	0.6	0.3	0.4	1-2	

Table: 5. Chemical properties of Blast furnace slag (Atika industrial zone)

Sr. No.	Description	Mini. Value		Maxi. value		Avg. value		Suggested value as per standards	Remarks
		CWA	XRF	CWA	XRF	CWA	XRF		
1.	CaO	16	15	24	26	21	20	30-43	
2.	SiO ₂	23	25	32	30	27	26	28-42	
3.	Al ₂ O ₃	18	18	24	22	21	20	5-22	
4.	MgO	5	5	10	9	7	7	4-15	
5.	Fe ₂ O ₃	22	24	28	29	25	26	8-10	
6.	SO ₃	0.5	0.4	0.8	0.9	0.6	0.7	1-2	

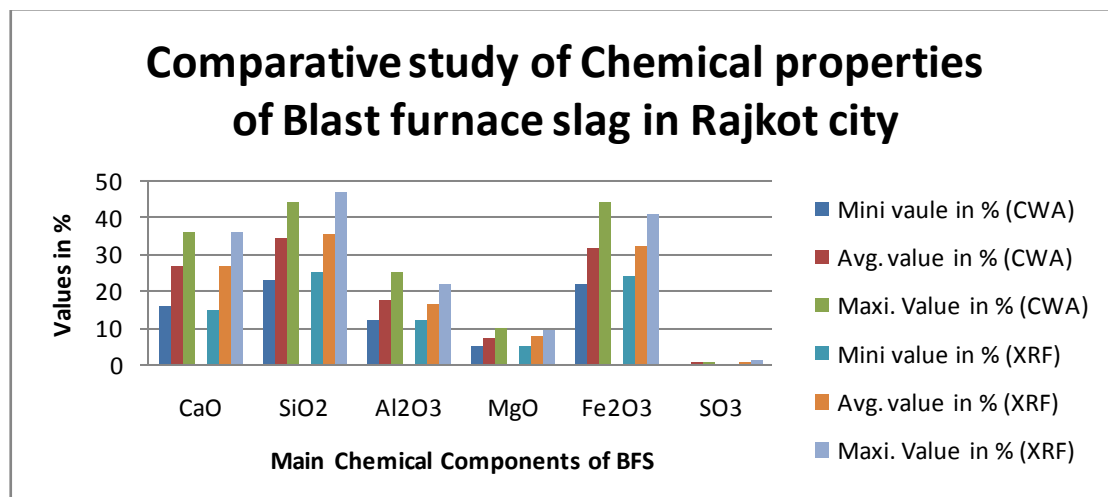


Fig. 1 Comparative study of Chemical properties of Blast furnace slag in Rajkot city

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

Physical Properties of BFS:

Physical properties of BFS is need to be entertain when it is used as fine aggregates in production of pavement concrete. Different physical properties are workout as per the guidelines and provision available from various international and national standards. The experimental results are narrated as per different industrial zone and its damping site within a nd around Rajkot city in Table-6 to Table -9. Based on the results from various locations, a comparative study of physical properties of BFS is shown in Table -10.

Table: 6. Physical properties of Blast furnace slag (Aji vasahat industrial zone)

Sr. No.	Description	Mini. value	Maxi. value	Avg. value	Suggested value as per standards	Remarks	
1.	Water Absorption in %	0.2	1.8	0.81	6.0		
2.	Specific Gravity	2.70	3.03	2.83	2.45 to 2.55		
3.	Mass per unit volume Kg/cm ³	Loose	1.31	1.51	1.40	1.2 to 1.3	
		Compacted	1.61	1.67	1.63	1.3 to 1.4	
4.	Iron Unsoundness (Immersion test)	Pass	Pass	Pass	Shall be no phenomena such as cracks, decomposition, muddiness, powdering		

Table: 7. Physical properties of Blast furnace slag (Samrat industrial zone - gondal road)

Sr. No.	Description	Mini. value	Maxi. value	Avg. value	Suggested value as per standards	Remarks	
1.	Water Absorption	0.4	2.8	1.63	6.0		
2.	Specific Gravity	2.59	2.91	2.74	2.45 to 2.55		
3.	Mass per unit volume Kg/cm ³	Loose	1.42	1.63	1.52	1.2 to 1.3	
		Compacted	1.62	1.76	1.68	1.3 to 1.4	
4.	Iron Unsoundness (Immersion test)	Pass	Pass	Pass	Shall be no phenomena such as cracks, decomposition, muddiness, powdering		

Table: 8. Physical properties of Blast furnace slag (Mandadungar industrial zone)

Sr. No.	Description	Mini. value	Maxi. value	Avg. value	Suggested value as per standards	Remarks	
1.	Water Absorption	0.2	2.4	1.16	6.0		
2.	Specific Gravity	2.58	2.88	2.72	2.45 to 2.55		
3.	Mass per unit volume Kg/cm ³	Loose	1.45	1.64	1.54	1.2 to 1.3	
		Compacted	1.71	1.77	1.74	1.3 to 1.4	
4.	Iron Unsoundness (Immersion test)	Pass	Pass	Pass	Shall be no phenomena such as cracks, decomposition, muddiness, powdering		

Table: 9. Physical properties of Blast furnace slag (Atika industrial zone)

Sr. No.	Description	Mini. value	Maxi. value	Avg. value	Suggested value as per standards	Remarks	
1.	Water Absorption	0.8	3.0	1.79	6.0		
2.	Specific Gravity	2.45	2.72	2.58	2.45 to 2.55		
3.	Mass per unit volume Kg/cm ³	Loose	1.39	1.46	1.43	1.2 to 1.3	
		Compacted	1.51	1.62	1.56	1.3 to 1.4	
4.	Iron Unsoundness (Immersion test)	Pass	Pass	Pass	Shall be no phenomena such as cracks, decomposition, muddiness, powdering		

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 3, March 2014

Table: 10. Comparative study of Physical properties of Blast furnace slag in Rajkot city

Sr. No.	Description	Mini. value	Maxi. value	Avg. value	Suggested value as per standards	Remarks	
1.	Water Absorption	0.2	3.0	1.35	6.0		
2.	Specific Gravity	2.46	3.04	2.72	2.45 to 2.55		
3.	Mass per unit volume Kg/cm ³	Loose	1.32	1.65	1.48	1.2 to 1.3	
		Compacted	1.51	1.77	1.66	1.3 to 1.4	
4.	Iron Unsoundness (Immersion test)	Pass	Pass	Pass	Shall be no phenomena such as cracks, decomposition, muddiness, powdering		

V. CONCLUSION

An experimental work is carried out to study the variation in chemical and physical properties of BFS and to check the possibilities and potentiality of this material to use as fine aggregates in production of pavement concrete by replacement of natural river bed sand. The primary characterization indicates the BFS have a enough suitability to utilize as a fine aggregate in production of concrete to enhance the strength and durability of the concrete by saving the natural resources like sand which is day by day become scarce. Chemical analysis results from the experiment reveals promising output except Fe₂O₃ with known existing international standards. The experimental results of Fe₂O₃ are on higher side as compared to the values available in literature for different site location. This leads to the checking of this BFS for the iron unsoundness. This parameter is already considered in physical analysis of this BFS and it is pass the iron unsoundness which ensures the suitability of BFS for required purpose. The physical analysis of the BFS produce encouraging results from experimentation and it is at par with known existing international standards. Out of four damping site considered for the study, Atika damping site shows wide variation of results in both chemical analysis as well as physical analysis. This variation is due to the small to large scale processing units present in that area as compare to other damping site which mostly have the large scale processing units. The results obtain in this study can be directly correlate with same type of BFS production site elsewhere and characterization of such site become very easy and cost effective.

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