

RESEARCH ARTICLE

BASALT AS BLOATED POZZOLANIC MATERIAL FOR CEMENT: PRELIMINARY ASSESSMENT OF BASALT FROM LASBELA DISTRICT, BALUCHISTAN

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ABSTRACT

The purpose of present study is to assess the physicochemical characteristics of bloated basalt for its sustainability in cement industry. Data reveal that the silica content in bloated sample is 66.82% which is 6% higher than the silica reported in an unbloated sample. Decreasing sulphur trioxide (SO_3) content in bloated basalt samples reduced the chances of internal sulfate attack. All chemical parameters of bloated basalt are within permissible limits and follow the corresponding standards. LOI and density of unbloated basalt is 2.9% and 0.1% that after heating reduced to 0.41% to 2.41 respectively. The compressive strength of the bloated sample shows slightly greater strength on 2, 7 and 28 days as compared to unbloated. By the addition of 5% bloated basalt sample in OPC the initial and final setting time increased from 15 to 20 minutes and from 5 to 10 minutes, respectively. Specific gravity shows a continuous decrease in the mass with the increase in temperature. The comparison of 5% bloated basalt powder by their replacement in OPC as a Pozzolanic cementitious material reveal that there is no major effect on the physico-chemical and mechanical properties of the cement.

KEYWORDS

Basalt, Bloat, Pozzolans, Cement industry, Concrete, Lasbela, Baluchistan.

1. INTRODUCTION

Pozzolan is defined as “a siliceous or siliceous and aluminous material, which itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing cementitious properties (Pozzolanic activity)” (Papadakis 2002). From this statement, it is clear that Pozzolanic material requires calcium hydroxide $Ca(OH)_2$ to form cementitious and strength products while cementitious material contains self-cementing properties. These natural materials require some heat energy and additives to become reactive. It is therefore all Pozzolanic materials are used in combination with Portland cement which provides $Ca(OH)_2$ for the activation of their hydraulic activities. Hydrated lime or material that can release by the hydration of Portland cement is then required to activate the natural Pozzolans as a binding material (Bakker 1999). Pozzolans are deficient in lime, which enables them to develop hydraulic properties. The use of natural Pozzolan in the concrete reduces the amount of calcium hydroxide available for the reaction, allowing the concrete to withstand the aggressive attacks by soils containing sulfates, as well as natural acidic water and seawater (Binici et al., 2007). It can also improve the concrete and mortar resistance to both sulfate attack and the alkali-silica reaction (ASR), which makes it essential to use in large concrete projects like bridges and dams (Gibbons 1997).

One of the root causes of concrete degradation is sulfate attack; this happens due to a set of chemical reactions that starts with the reaction of sulfate ions and calcium hydrate within the hardened cement paste while exposed to a sulfate environment (Mather 1982). Pozzolan is a siliceous material that can be used as an inexpensive cement in the mortar (Khan 2022). Artificial Pozzolans like blast furnace slag, fly ash and silica fume are industrial waste products and are found in excess quantities in industrialized countries. However, there are some naturally occurring

Pozzolans like shale, clay, basalt, volcanic ashes and diatomaceous earth which we can use after some treatment. Portland cement is the most common type of cement used in construction applications, but it is an expensive binder due to the high cost of production associated with the high energy requirements of the manufacturing process itself (Neville 1995). It is therefore these inorganic cheap materials with cementitious properties can be used as a partial replacement for Portland cement. Portland Pozzolanic cement (PPC) not only reduces cost but also have many potential technical benefits which include an increase in workability and durability, resistance against sulfate attacks and decreased in permeability. PPC also reduces the heat of hydration which in turn causes a decrease in the process of thermal cracking.

Cement is one of the most used construction materials. The production of cement is a chief contributor to greenhouse gases. The worldwide production of cement accounts for almost 7% of the total world carbon dioxide (CO_2) production, and from the projections made by cement manufacturers, this trend is expected to remain steady in the next decade (Memon et al., 2012). Furthermore, the production of cement is energy-intensive, one ton of cement production consumes about 1.6 MW h energy and discharge about one tons of carbon dioxide into the atmosphere (Neville, 2000). The worldwide CO_2 emission is severely affecting the earth's temperature, which causes climatic changes and global warming related issues (Humphreys and Mahasenan, 2002). It is, therefore, necessary to explore low-cost natural Pozzolan to solve this problem. Scientists and researchers all around the world are working to reduce carbon footprint. To deplete carbon emissions and maintain the strength and durability of concrete new trends are introduced. Among different technologies, the most effective way to reduce CO_2 discharge is to minimize the use of clinker by replacing it partially with supplementary cementitious materials (Yang et al., 2016). It is observed that the energy use and CO_2 emission of PPC are at least 20% less compared to OPC (Prakasan et al., 2020).

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The consumption of OPC on large scale not only increases CO₂ emission in the environment but also decreases the resources of limestone. For sustainable development of the cement and construction industry, we must maximize the use of natural and artificial Pozzolanic material. Due to these reasons, it is not only considered environmental friendly but also economical. This study investigated the potential use of a basalt extracted from Lasbela district in the bloated form in the production of blended cement. Bloated basalt not only retard CO₂ emission but also retard crushing cost as well as sustain the resources of limestone. This study targets the comparison of Pozzolanic Portland Cement with bloated and unbloated basalt. The sample's chemical, physical, mechanical and Pozzolanic characteristics were then examined to identify its sustainability. The present study is aimed to evaluate the feasibility of using bloated basalt as Pozzolanic material in the manufacture of Pozzolanic Portland cement for increased workability, and durability in a nature-friendly environment as well as a comparative study of bloated and unbloated basalt to reduce crushing cost, emission of carbon dioxide and increased its activity.

1.1 Geology of Study Area

The study area lies in Lasbela District, Baluchistan. It is a coastal district which is located in the south of Baluchistan. It is 7th largest district in Baluchistan in terms of land (Planning and development department 2011). It is bounded by Khuzdar district, Kirthar Range which divides it from Sindh, Hala offshoot of Pub Range and Arabian Sea on the North, East, West and South, respectively (Baloch et al., 2015). Lasbela District consists of nine tehsils Bela, Dureaji, Hub, Lairi, Uthal, Lakhra, Somiani, Gaddani and Kanraj however headquarter of district is located in tehsil Uthal. In terms of geography, archaeology, culture, environment, livestock, agriculture, coastal areas, forests, minerals, mines, hilly areas, plains, mountains, trough areas, industries, tourism, and defense strategic areas, this district of Baluchistan is very rich and diverse (Muhammad et al., 2022). The primary source of income of the people living in the district is agricultural activities like livestock, poultry farming, and fishing while the non-agricultural secondary sources of income are mining, industrial, and

commercial activities. Lasbela is to Baluchistan what Karachi is to Pakistan in terms of economic hub (Muhammad et al., 2022). As the district generates 90% of Baluchistan's industrial production and 70% of the country's overall earnings (Shaikh et al., 2020). Lasbela is adjacent to Karachi and famous for its historical places, coastal areas, mines, industries and military strategic base. (Muhammad et al., 2022). The rock sample was collected from an extensive deposit of basalt in Lasbela District, Baluchistan. The sample belongs to the shaly area of Parh Formation as shown in Figure 1 which was metamorphosed into a basalt locally by intense tectonic activity. Parh limestone represents Upper Cretaceous period in the Kirthar and Suleimn provinces of the Lower Indus Basin (Naseem et al., 2005). The Parh Limestone of the Turonain-Santonian age is well exposed in NNW-SSE trending Pab Range of Baluchistan, which merges into Kirthar Fold Belt northwards (Naseem et al., 2005). It belongs to a fine pelagic, shallow marine and deltaic Parh Group. Parh Group represents Sembar, Goru and Parh; belemnite-bearing shale, marl and limestone formations (Malkani, 2019).

In the type locality (Parh Range) it is about 268 meters thick (Khan et al., 2021). It is about 384 meters thick in the Mughal Kot Gorge while in some areas it attains a maximum thickness of about 600 meters (Shah, 2009; Khan, 2012). Blanford introduced the name Parh Limestone for the dominant limestone lithology in the Parh Range (Blanford, 1876). However, the detailed lithostratigraphy shows that the limestone is interbedded with shale (Khan, 2012). Lithologically, it is a very distinct unit composed of medium to thin-bedded hard limestone, with varying colors, such as white, cream, light grey, dark grey; it also contains subordinate marls and calcareous shale (Fatimi 1977; Khan 2012). It contains a conchoidal fracture which is distinguished from other limestone units, which gradually grade downwards into the black shale of the Sembar Formation (Fatimi 1977). The transitional contact between the two formations is mostly alluvium-covered (Khan 2012). The formation is widely distributed in parts of the Axial Belt and Lower Indus Basin. It has a wide lateral extension of more than 1000 km with many thick outcrops exposed from Bela in the south to Mughal Kot and Dera Ghazi Khan in the north (Jones 1961; Shah 2009).

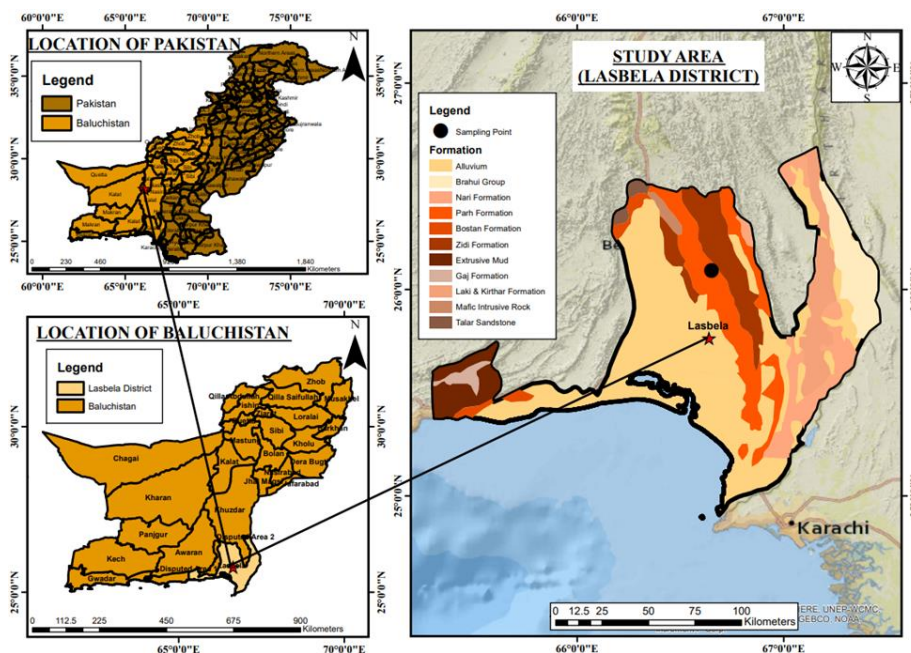


Figure 1: Geological map of the study area, Lasbela District.

2. MATERIAL AND METHODS

This study aims to evaluate the Pozzolanic properties of basalt. To conduct this experiment, samples were collected from an extensive deposit of basalt in Lasbela district, Baluchistan occurring at latitude of 26°5'31.00"N and longitude of 66°38'59.80"E. The color of sample which is collected from basalt mine varied from earthy brown to dark grey.

Samples were prepared in Epicinteron Laboratory. Bloated sample preparation involves the heating of sample at about 800°C which is then crushed and passed through sieve No. 200 to get fine ground powder. Unblotted sample preparation follows the same procedure without heating. Which is then investigated for the Pozzolanic activity. The physiochemical analysis of basalt samples was carried out in Chemical and Stone Testing Laboratory CWHR, Karachi. Chemical composition was

determined by gravimetric titration method using British standard EN-196-2:2005. The sample was also tested for the determination of loss on ignition (LOI) and specific gravity. The other modulus such as lime saturation factor (LSF), silica modulus (SM) and alumina modulus (AM) were calculated using Bogues equation. For investigation purpose, the samples were compared with standard limits of PS 232-2008. Blended cement is formed by the substitution of ordinary Portland cement with 5% unblotted and 5% bloated basalt as Pozzolans.

Finely ground unblotted and bloated basalt as Pozzolan were mixed with OPC in specified ratios of 5% with clinker of about 90%. While the content of limestone and gypsum was maintained constant at 5%. Further, for the comparison of effect after the addition of both basalt samples as Pozzolans in OPC compressive strength at 2, 7 and 28 days were tested, physical test and setting time were tested in a quality control department.

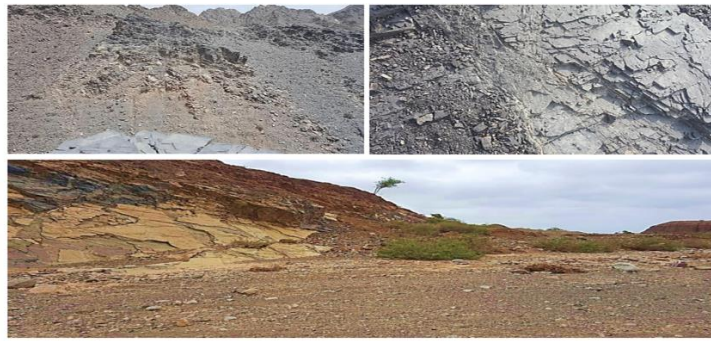


Figure 2: Mining site of basalt, Lasbela district, Baluchistan

3. RESULTS AND DISCUSSION

3.1 Chemical Properties of Basalt

Chemical results of basalt samples and its comparison with PS 232-2008 Standard Limits are summarized in Table 1. Findings reveal that the silica content in bloated sample is 66.82% which is 6% higher than the silica reported in unblotted sample. A decrease in sulphur trioxide (SO₃) content in bloated basalt samples reduces the chances of internal sulfate attack.

The oxides of sulphur are injurious to concrete (Prasad et al., 2006). The reaction of sulphate ions (SO₄²⁻) with hydrated cement products is a volume increasing reaction and is denoted as a sulphate attack on concrete (Prasad et al., 2006). LOI and density of unblotted basalt is 2.9% and 0.1%, respectively, after heating LOI and density is reduced to 0.41% to 2.41. As a result of the evaporation of volatiles, the loss on ignition and density is drop in bloated sample. All parameters of bloated basalt are within permissible limits and follow the corresponding standard.

Table 1: Chemical analysis of bloated and unbloated Pozzolan and its comparison with PS 232-2008 Standard.

Comparison of Bloated and Unbloated Slate						
Sr. #	Chemical Composition	Chemical Formula	Results (mass%) of unbloated Slate		Results (mass%) of bloated Slate	
			*P.L	*T.F	*P.L	*T.F
1	Silicon Dioxide	SiO ₂	54-68	60.2	56-70	66.82
2	Aluminum Oxide	Al ₂ O ₃	8-14.1	10.6	9.0-15	11.14
3	Ferric Oxide	Fe ₂ O ₃	3.5-9	7.49	4.5-10	8.45
4	Sulphur Trioxide	SO ₃	0.05-2.5	1.1	0.07-3.1	0.08
5	Calcium Oxide	CaO	4.0-6	1.9	1-5.5	3.2
6	Magnesium Oxide	MgO	0.07-1.2	0.09	0.09-1.5	1.1
7	Potassium Oxide	K ₂ O	1.5-2.7	1.6	1.6-2.9	1.72
8	Sodium Oxide	Na ₂ O	1.7-1.9	1.3	1.6-1.8	1.7
9	Loss on Ignition		2.5-10	2.9	0.5-1.5	0.41
10	Insoluble Residue		1.7	1.47	1.8	1.5
11	Density		-	2.75	-	2.41

*P.L (Permissible Limit) *T.F (Test Findings)

3.1.1 Comparison of OPC with PPC at 5% unblotted basalt and PPC with 5% bloated basalt

The chemistry of cement in general and Portland cement, in particular, depends upon the chemistry of its raw Material (Lea 1976). The comparative data of physical and chemical parameters of OPC with PPC at 5% unblotted basalt and 5% bloated basalt have been summarized in Table 2. The OPC cement of Power Cement Limited is composed of 90.00% clinkers, followed by gypsum and limestone in the ratio of about 5.0 % each. In this study, 5% unblotted and bloated basalt sample as Pozzolanic material was replaced with the clinker. To observe the impact of variations in the chemical and physical properties of raw materials on setting time and compressive strength. The LOI in OPC was about 3.35 % which slightly increased to 3.95 % and 4.12 % with the addition of 5 % unblotted and

bloated basalt powder, respectively. It is due to the fact that the reactivity of bloated Pozzolanic basalt is increased due to the increase in surface area after thermal cracking. However, the rising amount of silica was observed by the addition of unblotted basalt powder as Pozzolanic material up to 1% in PPC. The concentration of oxides in PPC with 5% bloated basalt varied in the order of CaO (61.95%) > Fe₂O₃ (4.39 %) > Al₂O₃ (4.29 %) > SO₃ (2.67 %) > MgO (2.34 %) > K₂O (0.76 %) > Na₂O (0.29 %) > Cl (0.0166 %). The results show that there is no major difference in chemical composition of PPC with bloated and unblotted basalt. All parameters are slightly varying up to < 1 %. The comparative study of chemical and physical parameters showed that the replacement of unblotted basalt as Pozzolanic material with bloated is feasible for the manufacturing of PPC. The above results and discussion suggest that there were no significant differences between all these factors and no major effect in the character of PPC with 5% unblotted basalt and PPC with 5% bloated basalt was observed.

Table 2: Comparison of Ball Mill Samples with Pozzolan Un-Bloated & Bloated.

Contents (%)	Material Ratio (%)			Material Ratio (%)				Material Ratio (%)			
	Clinker	Gypsum	Lime stone	Clinker	Gypsum	Lime stone	Pozzolana	Clinker	Gypsum	Limestone	Pozzolana
	90.0	5.0	5.0	85.0	5.0	5.0	5.0	80.0	5.0	5.0	10.0
L.O.I	3.4			3.95				3.67			
SiO ₂	20.36			21.71				24.52			

Table 2 (Cont): Comparison of Ball Mill Samples with Pozzolan Un-Blotted & Blotted.

Al ₂ O ₃	4	4.22	4.67
Fe ₂ O ₃	4.25	4.29	4.42
CaO	63.41	61.54	58.6
MgO	2.31	2.21	2.22
K ₂ O	0.65	0.68	0.73
Na ₂ O	0.21	0.25	0.34
SO ₃	2.59	2.68	2.65
Cl	0.0243	0.0187	0.0168
LSF	95.5	87.02	73.66
SM	2.47	2.55	2.7
AM	0.94	0.98	1.06
C ₃ S	63.03	43.41	6.98
C ₂ S	10.85	29.53	65.03
C ₃ A	3.42	3.92	4.9
C ₄ AF	12.93	13.04	13.45
Free Lime	1.08	1.2	1.26
Physical Tests:			
Blaine cm ² /gm.	3505	3554	3554
Residue on 90μ	-	-	-
Residue on 45μ	3.1	2.7	2.9
Expansion in mm.	1.00	Nil	1.00
Consistency%	26	26.5	28
Setting Time:			
Initial Setting (mints.)	230	245	250
Final Setting (mints.)	285	290	295
Compressive Strength:			
2 Days Mpa	24.20	21.39	20.79
7 Days Mpa	37.35	34.73	35.21
28 Days Mpa	45.53	43.77	43.27

3.1.2.1 Lime Saturation Factor (LSF)

Lime saturation factor of the OPC sample is found to be 97.72, which is in the desirable limit (90-98%). By the addition of 5% unblotted and 5% blotted Pozzolan, LSF decreases to about 89.65% and 88.01%, respectively. To produce cement, the lime saturation factor (LSF) plays an important role, because it contains CaO which is the primary constituent of cement (Ingram and Daugherty, 1991).

It contributes to the compressive strength of the cement. LSF in PPC with the addition of 5% blotted and unblotted basalt is decreases because of increasing silica content. Excess or low amount of lime saturation factor results in undesirable effects that affect the strength, durability and workability of the cement.

Generally, an excessive amount of silica content due to its high hardness creates abrasion and frictional abrasion creates heat energy which affects the production of clinkers. However, no such effect has been reported in this study.

3.1.2.2 Silica Modulus (Silica Ratio)

The Silica modulus of OPC sample is found to be 2.51% which is slightly increased to 2.56% by the addition of 5% unblotted Pozzolan. It indicates that there is no significant effect of unblotted basalt on the silica ratio. The substitution of 5% blotted basalt powder gives a 2.56% silica ratio. The increased amount of silica results in the slow setting and higher initial and final compressive strength.

3.1.2.3 Alumina Modulus (Alumina Ratio)

Alumina Modulus was reported to be 0.89 in OPC. By mixing 5% blotted and 5% unblotted Pozzolan it is slightly increased to 0.984% to 0.977%, respectively. The alumina ratio should be in the range of 1 to 4% to

produce cement as per ASTM-C150. Results of the present study indicate that the substitution of OPC with 5% blotted and 5% unblotted Pozzolan gives no major variations in alumina ratio.

3.1.2.4 Free Lime

The amount of free lime in OPC is found to be 1.12% which is slightly increased to 1.2 and 1.16% when replacing it with 5% unblotted basalt and 5% blotted basalt powder. Excess free lime results in undesirable effects such as volume expansion, increased setting time or reduced strength (Nuhu et al., 2022). The above comparison shows that the substitution of 5% blotted Pozzolans gives less free lime as compared to unblotted basalt.

3.2 Physical Properties

3.2.1 Blain Test

The blain test value of OPC was about 3485 cm² /gm. However, by the addition of 5% unblotted and 5% blotted ground basalt sample, it was reported to be 3554 cm² /gm and 3579 cm² / gm, respectively. This is due the fact that finer cement (due to its larger surface area) is more reactive with water at early ages (Dale et al., 2008). It has been noted that, for cements of specific surface of 2000–3600 cm² /gm, an increase of 1 % in specific surface results in a 2 % and 1 % increase, respectively, in 7- and 28-day strength (Troxell et al., 1968).

3.2.2 Residue

Insoluble residue content in OPC was retained up to 3.25 % on 45μ. Contrary to that, the addition of 5% unblotted and 5% blotted ground basalt, the IR value varied from 2.7 to 2.85 % respectively. As per ASTM-C150 for manufacturing of cement the insoluble residue should be 0.75 % so the IR was high both in unblotted and blotted basalt blended cement.

3.2.3 Expansion

In OPC, the expansion was found to be 1.00 mm. Conversely, there was no expansion reported in the basalt admixture at 5 % unbloated basalt. Surprisingly, as shown in Table 2 the results remained constant by mixing 5% bloated basalt powder.

3.2.4 Consistency

Consistency was about 27 % in OPC and by the addition of 5 % unbloated basalt consistency slightly decreased to 26.5%. Contrary to that, consistency increased to about 28% with the substitution of 5% bloated ground basalt. The standard consistency range for OPC is 25-35 %. Hence, consistency of both OPC and PPC was within permissible limits.

3.2.5 Setting Time

Initial and final setting time of OPC were about 230 and 285 minutes respectively. By the addition of 5% unbloated and bloated basalt sample, the initial setting time increased from 15 to 20 minutes and the final setting time increased from 5 to 10 minutes.

An increase in the initial and final setting times is attributed to high content of SO₃ due to the formation of sulphuric anhydride (Paraskeva et al., 2007). From the above observations we concluded that cement with

5% unbloated basalt can be replaced cement with 5% bloated basalt material.

3.2.6 Compressive Strength Test

Compressive strength tests were performed on three samples each of OPC and PPC (at 5% unbloated and bloated basalt) the results of which have been summarized in Table 2. The compressive strength of OPC in the initial 2 days is about 24.30 Mpa which was increased up to 36.95 Mpa and double (46.14 Mpa) after 7 and 28 days. On the other hand, the substitution of 5% clinkers with unbloated and bloated basalt reveals that the bloated sample shows slightly greater strength on 2, 7 and 28 days as compared to unbloated.

This increase in strength is due to the increased quantity of alkalis. Concrete strength data indicate that for cements low in alkali and aluminate content, increasing the SO₃ to 3.6% increases the strength loss at 180 days (Zayed et al., 2004). Figure 3 shows that there is no major variation in compressive strength of both in initial and final stage. Comparison of OPC and PPC revealed that compressive strength decreased during initial days (2 and 7 days) in PPC but increased after 28 days which is attributed to the occurrence of silica and the calcium hydroxide in the hardened cement paste to produce additional C-S-H (Taylor 2008; Bustos et al., 2015).

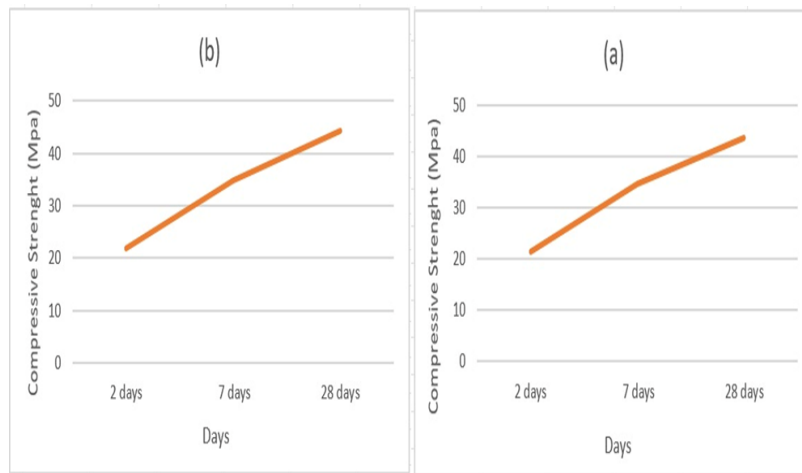


Figure 3: The graphs showing the compressive strengths of (a) PPC with 5% unbloated basalt and (b) PPC with 5% bloated basalt.

Table 3: Comparison of specific gravity and weight of basalt sample at different temperatures.

Parameters	Before Heating	After Heating	Difference (%)
At 350°C			
Specific Gravity	2.7	2.66	0.04
Weight in Grams	46.51	45.34	1.17
At 550°C			
Specific Gravity	2.68	2.48	0.2
Weight in Grams	63	61.49	1.51
At 650°C			
Specific Gravity	2.76	2.67	0.09
Weight in Grams	60.17	59.19	0.98
At 800°C			
Specific Gravity	2.54	2.41	0.13
Weight in Grams	45.98	42.13	3.85

3.2.7 Specific Gravity

The results of specific gravity in Table 3 show that there is a continuous decrease in the mass and specific gravity of a basalt with the increase in temperature. There is a minor change in the parameters of basalt at 350°C while at higher temperature of about 800°C major variation was observed. This major variation is due to the decomposition of hydroxyl and carbonate compounds.

The removal of these compounds and volatiles causes the ultimate increase in the silica content of the substance. Beyond threshold

temperature, because of the process of thermal cracking, porosity develop and the tensile strength of a substance decrease. This eventually cause ease in the crushing and reduce energy cost.

4. SUMMARY AND CONCLUSION

The comparison of 5% bloated basalt powder with their replacement in OPC as a Pozzolanic cementitious material reveal that there is no major effect on the physical and chemical properties of the cement. The addition of this bloated basalt in OPC will not affect the properties of cement in terms of compressive strength, setting time and other physical properties.

It is concluded that naturally occurring bloated basalt and Pozzolanic material is a good substitute of granular blast furnace slag, good for making durable Pozzolanic admixture for cement replacement. It is good cement saving material. This bloated basalt as Pozzolans can be used for massive and water-associated construction projects such as dams, because it lowers the heat of hydration. An improvement in resistance to thermal cracking is also obtained due to the lowering of heat of hydration.

Further, the use of PPC with 5% bloated basalt also reduce the emission of carbon dioxide which deplete the greenhouse gases in the atmosphere. After heating basalt to high temperature because of the process of thermal cracking, the specific gravity and toughness of bloated basalt is also reduced which causes ease in crushing and reduces energy cost. It is also concluded from the comparison of bloated and unblotted basalt that bloated basalt increases the activity of PPC.

Thus, to improve the mechanical and environmental properties of PPC it is a good replacement of unblotted basalt in PPC. There are extensive resources of basalt available in the Lasbela district. A detailed study is needed to evaluate and fully understand the characteristics of Pozzolanic material from Bela region to utilize in cement industry.

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