1981 (0587) / (0613)

Use Of Basalt Fines in Making Building Bricks

Mohan Rai & Dinesh Chandra

Central Building Research Institute, Roorkee

511 BRICK (06)

Abstract :

Basalt, an igneous rock occuring in the Deccan plateau was formed by the outbursting of volcanic energy resulting into lavas in a large part of Indian penninsula. This volcanic rock covers a vast area of our country—Basalt is generally used as building stones and its gravels are used as road ballast and concrete aggregate. During crushing of basalt stone, a huge amount goes waste in the form of fine dust. At present this fine material has no specific use in our country.

The Central Building Research Institute, Roorkee has shown that this basalt fines could be used as an opening material instead of grog in making bricks from highly clayey soils such as black soils which pose problems of drying cracks. The addition is advantageous in producing not only building bricks but engineering bricks of compressive strength.

Introduction :

Basalt an igneous rock occurring in the Deccan plateau was formed by the outbursting of volcanic energy resulting into lavas in a large part of Indian peninsula. This volcanic rock also called Deccan Trap covers an area of about 3,200,000 sq. km in Gujarat, Madhya Pradesh, Goa, Andhra Pradesh and Maharashtra,

Being dense, hard & durable, basalts are used fairly extensively as building stones in areas where they occur in large masses, but being dark, in colour, they are usually not preferred as facing stones for decorative purposes in buildings. Basalt is also an excellent material as road metal for macadam and tarred roads. Nevertheless several new uses of basalts in making glass ceramics and chemical resistant building materials have also been proposed and which will be described later.

Basalt stones and dust available after crushing and sieving can be utilised in the development of ceramics, concrete, pozzolana and mineral fibre etc. Gilbert and Hughes [1] have developed heavy clay products using 95 percent basalt fines (-200 mesh) and an organic binder and shaping into tiles but the tiles cracked during firing. Further these workers mixed basalt fines 50-70 percent with clay or shale and fired the product at 1110°C. These bricks were found to be more abrasion resistant than other engineering bricks.

In Australia, basalt is quarried for road making and concreting. During quarrying about 10 per cent of the stones becomes too fine and goes waste. Tauber [2] has used these fines as a fluxing constituent and developed building ceramics by slip casting and firing at 1050°C. A patent [3] has also been taken up for the manufacture of strong ceramics tiles composed of granular basalt and clay. Under this process mixture of (-3cm) basalt (30-50), powdered basalt (16-30), powdered glass (16-20), clay (16-20) and water (10-14) percent were cast, dried and fired at 1050°C. These semiglazed tiles had 2.05—2.10 gm/cc density, modulus of rupture 43—54 kg/cm² and o.8—2.5 percent total shrinkage. Abrasion resistant fired tiles have also been developed by Tikeshi and Shingeru in Japan [4] from basalt rock by crushing and adding 3—30 percent bonding clay and sodium silicate or phosphoric acid as binder and firing the product at 900—1100°c. These tiles had higher abrasion resistance (25 times) and much better thermal impact resistance than local clay tiles.

Buerger [5] has developed ceramic bodies by mixing (10—80), igneous material (20—90) and foaming agent <1 percent weight, moulding and firing at 750—1500°c. Basalt 41 (<200μ), glass 18 (<150μ) and ultrafine silicon carbide (0.05gm) were dry mixed, moulded and fired at 940°c for 5 hrs. The ceramic product had density 1.8 gm/cc.

It can be seen from the abeve literature survey that no detailed work has been done so far on the utilisation of basalt in ceramic industry of India. Hence it was considered appropriate to initiate a research programme in this Institute in that direction. This paper describes the work done in the Institute.

Experimental :

Samples of basalt stone dust and locally available soils for the present study were collected from Bhopal, Indore and Nagpur regions. These are black cotton soil areas, so the problem of drying cracks in bricks usually occurs at all these places.

Chemical compositions (Table 1&2), particle size and plastic properties (Table 3), Differential Thermal Analysis (Fig.1) X-ray Diffraction Analysis (Table 4 & 5) and petrographic analysis of the three soils and basalt samples were determined in the laboratory. The DTA of these samples were carried out using the Leeds and Northrup Thermal Analyser by keeping the heating rate of 10°C/min and chromel alumel thermocouple. The X-ray diffraction analysis were carried out by using X-ray Diffractometer (Philips 1730) by keeping the scanning speed at 1°/min, Chart speed 0.5 cm/min. range 2000 C/s, time constant 2 and copper target with nickel filter. The petrographic analysis was carried out by using the 'panphot Leitz optical Microscope'.

Table-1

Chemical Analysis of Basalt Fines

Contents %	Basalt Fines Nagpore	Bhopal	Indore
SiO_2	49.13	46.90	48·49
Al_2O_3	12.35	16.00	16 60
Fe_2O_3	19.69	16.20	15.80
TiO_2	1.58	1.03	0.89
CaO	10.21	12.20	12.10
MgO	5.00	3.20	3.12
Alkalies	0.82	0.33	0.46
LoI	1.33	4.68	2.31

Table-2

Chemical Analysis of the Soils from Nagpur and Bhopal

Contents	Nagpur Soil	Bhopal Soil
SiO_2	54.02	57.94
Al_2O_3	13.01	17.20
Fe_2O_3	18.51	8.40
CaO	4.41	2.40
MgO	2.39	2.00
Alkalies	0.41	0.11
LoI	7.21	12.05
SiO_2/Al_2O_3	7.06 : 1.0	5.7 : 1.0
SiO_2/Sesquioxide	3.7 1.0	3.5 : 1.0

Table-3

Particle Size Analysis and Atterberg Limits of the soils

Characteristic	Nagpur Soil	Bhopal Soil
Clay, %	42.4	45.0
Silt, %	25.1	30.4
Sand. %	32.5	24.6
Liquid Limit, %	40.3	44.5
Plastic Limit, %	24.2	26.4
Plasticity Index,	16.1	18.1
Activity Coefficient	0.37	0.40
Casagrande's Plasticity Classification	CL	CL
Textural Classification	Clay group	Clay group
Skempton's Classification	Group 1	Group 1

Various mixes of basalt and soil (both passing 0.5 mm) from Nagpur region were prepared and cubes of size 2.5×2.5×2.5 cm were hand moulded and dried in the sun. During drying it was noticed that cubes of pure soil and 90 percent soil with 10 percent basalt fines cracked. The rest of the cubes were fired in a laboratory electric furnace at 1000, 1050 and 1100°C for two hours soaking time. On the basis of the preliminary results thus obtained, briquettes of different mixes containing basalt and soil were moulded and dried in the sun. The briquettes having 80 percent soil and 20 percent basalt fines by volume were found to crack in drying period. The same was the result in the case of 20% grog addition to these soils. The remaining briquettes were fired at 1000, 1050 and 1070°C in the laboratory furnace with 4 hrs soaking period. The full size bricks of 70:30, 60:40 and 50:50 mixes of soil : basalt were moulded and dried inthe sun. The bricks of 70:30 mix were cracked during drying. So the bricks having 60:40 and 50:50 composition were finally fired at 1000°C. The same experiments were carried out with basalt and soil from Bhopal and Indore regions. The results obtained have been given in Tables 7 to 10.

Results And Discussions

Mineralogical ,

Basalts

The chemical analysis of basalts from Nagpur, Bhopal and Indore regions shows that in these samples SiO_2 contents are in the range of 46—49 percent, Al_2O_3 12-17.6, Fe_2O_3 15.8-19.7, CaO 12.1-13.2 and MgO 3.2-5.0 percent. The alkali content in Nagpur basalt is as high as 2.62 percent while in other basalts it is 0. 16—0. 32 percent. The X-ray diffraction analysis of the basalts (Fig.2 to 4) shows the presence of quartz, magnetite, hematite, plagioclase, orthoclase and pyroxene as the main constituents and calcite, hornblende, ilmenite, olivines and amphiboles as accessory minerals. The petrographic analysis shows the presence of iron minerals as inclusion in the Pyroxene and plagioclase crystals. Ilmenite/hematite occur as grains and dusts in the glassy ground mass. Amorphous isotropic product palagonite is occasionally found as filling material. The DTA results of these samples confirm the presence of biotite, anorthite, antigorite, magnetite and quartz (Fig.1).

Table-4

X-ray Diffraction Data of the Basalt Stone Dust Samples

d (Å)	Nagpur I/I_1	Bhopal I/I_1	Indore I/I_1	Possible Phases
16.05	7	—	—	Sauconite
6.50	3.5	2.0	2.0	Labradorite
4.62	—	4.5	4.0	Tremolite
4.55	—	—	4.0	Tremolite
4.04	10	11	9.0	Labradorite, Orthoclase, Anorthite, Cristobalite
3.92	3	3	3	Forsterite, Albite
3.75	11	12 5	13.5	Labradorite, Fayalite, Ilmenite
3.62	7.0	7.0	8 0	Antigorite
3.34	6.5	9.0	6.0	Quartz, tremolite, orthoclase
3.21	59.0	43.0	47.0	Labradorite, Albite, titanite, kyanite
3.13	8.0	8.0	7.5	Anorthite, Enstatite
3.02	16.0	19.0	3.0	Augite, Magnetite
3.00	—	—	16.0	Augite
2.93	12.5	13.0	15.0	Magnetite, Augite, titanite
2.89	7.5	9.0	—	Enstatite
2.83	7.0	4.5	5.5	Enstatite, fayalite, Cristobalite
2.70	2.0	—	—	Hornblende, Sauconite
2.66	3.0	—	4.0	Hornblende, Aragonite, Sauconite
2.61	3.0	—	2.0	Carnegieite
2.58	9.0	8.0	7.5	Ilmenite, Augite, titanite
2.52	16.0	9.5	20.0	Anorthite, Chrysotile, Augite, Magnetite Forsterite, Antigorite
2.43	—	3.5	3.0	Chrysolite, Quartz, Cristobalite
2.35	—	—	3.0	Quartz
2.28	3.5	3.5	4.0	Augite, Quartz
2.22	—	—	2.0	Ilmenite
2.13	9.5	10.5	10.0	Augite, Quartz
2.02	—	4.0	13.0	Augite Aragonite
1.99	2.5	3.0	3.0	Augite, Kyanite
1.88	3.5	5.5	3.0	Ilmenite, Albite
1.83	4.0	4.5	4.0	Quartz, Augite, Albite
1.79	3.0	3.5	4 0	Albite, Quartz
1.77	4.0	3.0	4.0	Fayalite Forsterite
1.75	—	3.0	4.0	Ilmenite, Augite, Chrysolite, Forste-
1.63	6.0	6.0	6.0	rite, Fayalite Augite Cristobalite, Ilmenite, Tridymite
1.58	—	—	3.0	Trimolite
1.54	3.0	4.0	—	Quartz, Sauconite
1.48	4.0	—	5.0	Enstatite, Magnetite, Carmegiete
1.45	3.0	—	3.0	Hornblende
1.43	5.0	—	3.5	Augite, hornblende

Soils

The chemical analysis of Nagpur soil shows the presence of higher amount of Fe_2O_3 and the Si_2O/Al_2O_3 ratio as 7.06 and SiO_2/sesquioxide ratio 3.7. The higher amount of Fe_2O_3 may be either due to free Fe_2O_3 $FeO(OH)_3$, or nontronite clay mineral. The DTA result of this soil as given in Fig.1 shows two endothermic peaks at 140 and 540°c and two exothermic peaks at 380 and 890°c with a small dent at 800°c. This shows the presence of montmorillonitic group of clay minerals mainly nontronite as predominant mineral and chlorite clay mineral as accessory minerals. The exothermic peak at 380°c may be due to the presence of iron gel. The X-ray diffraction results (Fig.6) of the clay fraction of Nagpur soil and glycerol treated sample confirm the presence of montmorillonitic group of clay minerals with chlorite, quartz and feldspar as accessory minerals.

The chemical analysis of Bhopal soil shows SiO_2/Al_2O_3 and SiO_2/sesquioxide ratios to be 5.7 and 3.56 respectively. The thermogram of clay fraction of this soil (Fig.1) shows two endothermic peaks at 140 and 580° and an exothermic peak at 900°c with two small dents at 350—370° and 700—730°c. This thermogram shows the presence of montmorillonitic group of clay minerals with some amount of illite and gibbsite. The X-ray diffraction pattern of the clay fraction (Fig.5) suggests the presence of montmorillonite, illite, chlorite and feldspar.

Physico-Chemical properties of Soils

The particle size analysis of soils from Nagpur and Bhopal regions shows the clay size particles and total fines of the order of 42·45 and 67.5-75.4 percent respectively. The textural classification of these soils shows that these are of clayey nature and according to Skempton's classification [6] these soils belong to group I i.e. inactive class, which confirms the presence of above mentioned clay minerals. The Atterberg's limits of these soils indicate that according to Casagrande's plasticity chart, they belong to CL group.

Properties of Bricks

The results obtained after drying and firing of the cubes of size 2.5×2.5×2.5 cm made from Nagpur basalt and soil and fired at 1000, 1050 and 1100°C as given in Table 6 indicate that the compressive strength of the cubes increases with increase in proportion of soil when fired at 1000 or 1050°C which may be due to the inert behaviour of baslat and some vitrification of soil. The water absorption decreases and bulk density and total shrinkage increase with soil content of the mix. When these cubes are fired at 1100°C, the strength increases for the mixes upto 50:50 composition and then decreases which may be attributed to the formation of more vitrified matter due to fusion of basalt; the fusion temperature of basalt was found to be 1150°C. The compactness of the mix may be greater at 50:50 compositon. Some of the cubes showed good glassy surfaces and a few melted also. The water absorption decreases with increase in soil content of the mix. During drying of briquettes having different proportions of basalt and clay it was observed that the briquettes containing 80 percent soil and 20 percent basalt from Nagpur region cracked due to high drying shrinkage. On the addition of basalt above 30 percent, the drying cracks were removed, confirming the use of basalt as an opening material in plastic soils in the same manner grog (calcined clay) or coal ash is used. But as compared to 'grog' the addition of basalt is more advantageous because its addition does not require any extra labour and cost of firing and grinding.

When the briquettes were fired at 1000,1050 and 1070°C the compressive strength was found maximum for 50:50 composition (Table 7) but further decreased with increase in the addition of basalt. The briquettes having 30 percent grog and 70 percent soil and fired at 1000°C have the compressive strength of 100kg/cm², while the briquettes having 50percent basalt and 50 percent soil show the eompressive stregnth of 169 kg/cm² at the same firing temperature. No doubt the compressive stregnth of briquettes increases with increase in the firing temperature and is abruptly high at 1000°C with dark brown glazy surfaces. This experiment shows that the vitrification range of basalt is very narrow and this repuires proper attention.

The briquettes made from Bhopal basalt and soil show that 30 percent addition of basalt or grog to the soil removes drying cracks. The compressive strength of the briquettes fired at 1000°C for 5 hours was found to be in the range of 140-150 kg/cm² when 30 to 50 percent basalt or grog was mixed with the soil (Table 8). As the addition of basalt or grog increases, the

Table-5

X-Ray Diffraction data of Nagpur and Bhopal Soils

Sl. No.	Bhopal Soil Clay Fraction As Such d (Å)	Bhopal Soil Clay Fraction Treated with Glycerol d (Å)	Nagpur Soil Clay Fraction As Such d (Å)	Nagpur Soil Clay Fraction Treated with Glycerol d (Å)	Possible Mineral
1.	14.5	17.0-19.2	—	—	Illite+Montmorillonite (Random mixture)
2.	—	—	15	17.7	Montmorillonite
3.	12.6	12.6	—	—	Montmorillonite
4.	10.2	10.3	—	—	Illite+Montmorillonite (Random mixture
5.	—	—	9.11	9.14	Montmorillonite
6.	7.13	7.10	7.13	7.16	Chlorite
7.	5.01	5.04	—	—	Illite+Montmorillonite
8.	4.48	4.45	4.44	4.46	Illite+Montmorillonite
9.	4.26	4.25	4.27	4.28	Quartz
10.	3.53	3.52	3.53	3.54	Chlorite
11.	3.35	3.35	3.36	3.36	Quartz
12.	3.24	3.23	3.22	3.23	Plagioclase
13.	2.49	2.49	—	—	Illite
14.	2.45	2.45	2.44	2.44	Montmorillonite
15.	2.05	2.05	—	—	Illite+Montmorillonite
16.	1.99	1.97	—	—	Illite+Chlorite
17.	1.81	1.81	1.80	1.80	Quartz

Tabel-6

Some Physical Characteristics of Cubes made from Nagpur Basalt and Soil and Fired at Different Temperature (Size of Cube - 2.5x2.5x2.5 cm)

Composition (by vol)		Firing Temperatures 1000°C				1050°C				1100°C			
Basalt	Soil	Sh.	C. S.	W. A.	B. D.	Sh.	C, S.	W. A.	B. D.	Sh.	C. S.	W. A.	Firing result (Surface texture
90	10	0.20	25.6	13.6	1.66	1.43	30.0	12.9	1.70	—	230	3.5	Rough
80	20	2 29	58.0	13.0	1.85	2.90	62.0	12.6	1.88	—	425	2.8	Rough
70	30	7.70	67.0	11.9	1.83	10.2	69.0	11.4	1.90	—	610	1.5	Smooth
60	40	12.5	69.0	11.8	1.80	13.6	73.2	11.3	1.92	—	675	1.0	Smooth
50	50	18.5	73 0	11.6	1.88	19.3	80.1	11.0	1.94	—	870	0.90	Glazy
40	60	21.9	78.0	11.3	1.89	22.4	85.3	10.6	1.95	—	710	0.81	Glazy
30	70	26.0	90.0	10.2	1.93	27.7	95.4	9.9	1.97	—	475	0.67	Glazy
20	80	33.2	110.0	9.8	1.98	34.3	124.0	9.5	1.99	—	425	0.60	Melted
10	90	Cracked during drying				—	—	—	—	—	—	—	—
—	100	Cracked during drying				—	—	—	—	—	—	—	—

Sh = Total Shrinkage (%)
W. A. = Water absorption (%)
C. S. = Compressive strength (kg/cm²)
B. D. = Bulk Density (gm/cc)

Tabel-7

Physical properties of Briquettes Made from Nagpur Soil and Basalt and Fired at Different Temperatures

Composition Basalt	Soil	Firing Temp. (°C)	Total Shrinkage (%)	Water Absorption (%)	Bulk Density (gm/cc)	Compressive Strength (kg/cm²)
—	100		Badly cracked during drying			
20	80		Cracked during drying			
30	70	1000	Cracked in firing			
50	50		17.5	13.9	1.86	169
70	30		10.1	15.8	1.83	107
50	50		19.3	10.2	1.89	193
70	30	1050	12.0	11.7	1.85	132
80	20		11.4	12.0	1.84	120
70	30	1070	27.4	2.85	1.96	775*
30	70		Cracked during firing			
50	50	1100	35.8	2.1	2.06	1610*
70	30		30.3	2.3	2.04	1670*
Grog						
30	70	1000	22.7	16.8	1.80	100

* All the briquettes were badly vitrified with dark brown glazy surface and deshaped.

Table-8

Physical properties of Briquettes Made from Bhopal Basalt and Soil and Fired at Different Temperature

Composition Basalt	Soil	Firing Temp. (°C)	Total Shrinkage (%)	water Absorption (%)	Bulk Density (gm/cc)	Compressive Strength (kg/cm²)
—	100		Badly cracked during drying			
20	80		Cracked duringdrying			
30	70	1000	22.7	11.6	1.82	150
50	50		17.5	11.0	1.84	135
70	30		9.8	10.7	1.88	104
30	70		30.8	13.0	1.86	270
50	50	1050	26.3	12.2	1.90	293
70	30		16.8	11.8	1.92	257
50	50		36.0	0.85	2.49	1120*
70	30	1070	30.9	1.07	2.47	1015*
75	25		28.0	0.76	2.52	812*
Grog						
20	80		Cracked during drying			
30	70		30.6	17.5	1.66	145
40	60	1000	28.3	14.8	1.68	140
50	50		22,1	13.2	1.73	152
70	30		13.2	14.0	1.70	120

* All the briquettes were vitrified with glazy surface.

Table 9

Physical properties of Briquettes Made from Indore Basalt and Soil and Fired at Different Temperatures

Composition Basalt	Soil	Firing Temp. (°C)	Total Shrinkage (%)	Water Absorption (%)	Bulk Density (g/cc)	Compressive Strength (kg/cm²)
—	100		Cracked during drying			
30	70	1000	18.5	19.3	1.83	112
50	50		15.1	16.0	1.86	141
50	50		25.0	8.6	1.92	541*
70	30	1050	19.2	10.3	1.98	522*
Grog						
30	70		21.4	16.8	1.81	105
50	50	1000	17.4	14.1	1.85	120

* Briquettes with smooth glassy surfaces.

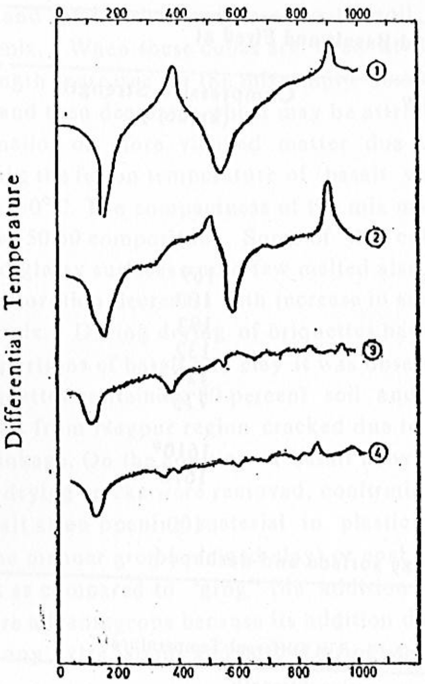

Fig. 1 · Thermograms of (1) Nagpur soil, (2) Bhopal soil (3) Nagpur basalt and (4) Bhopal basalt samples.

strength reduces about 100 kg/cm². The strength of the briquettes fired at 1050°C was about double as compared to the briquettes fired at 1000°C. When these briquettes were fired at 1070°C, the strength abruptly increased from 293 to 1120 kg/cm² in the case of 50:50 composition and the surfaces of the briquettes were also glazy.

In the case of the briquettes made from Indore basalt and the soil, the compressive strength was found to be 05—140 kg/cm² when basalt or grog was used as an opening material (Table 9). The addition of 30 percent basalt or grog was found to be optimum to remove the drying cracks. When the briquettes containing basalt and soil were fired at 1050°C the strength increased abruptly which indicates the fusion of basalt at this temperature. The strength of these briquettes increased with the firing temperature.

The briquettes fired at 1070 to 1100°C having glazy surface were found to be acid resistant and the loss on boiling in HCl was found to be maximum 2 percent when tested as per IS standard (4457—1967). The acid resistance of Nagpur basalt (unfired) was obtained to be

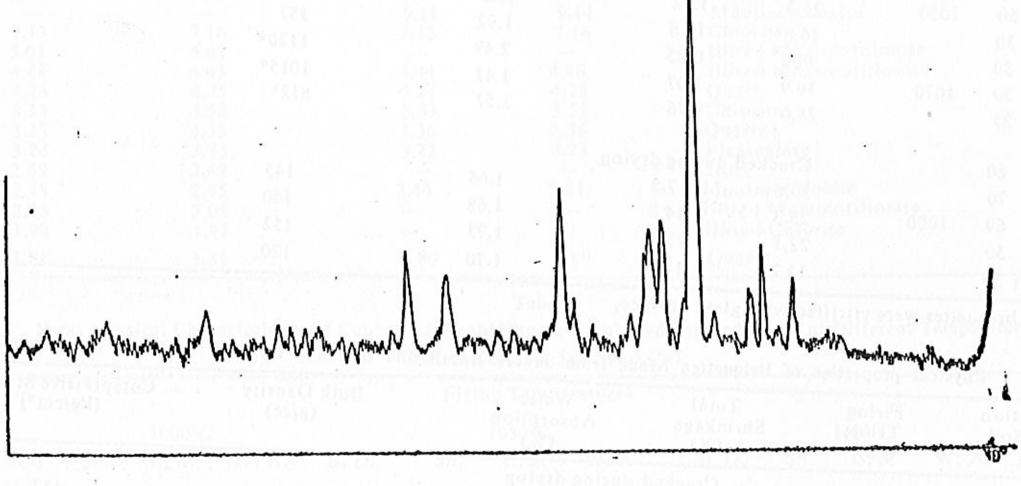

Fig. 2 · X-ray diffractogram of Bhopal basalt.

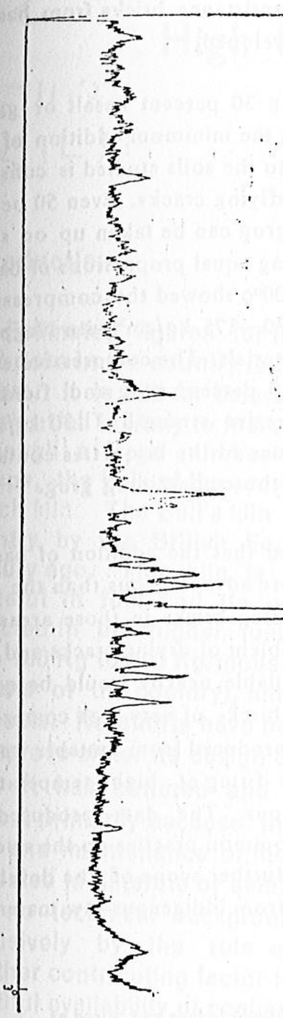

Fig. 3 X-ray diffractogram of Nagpur basalt.

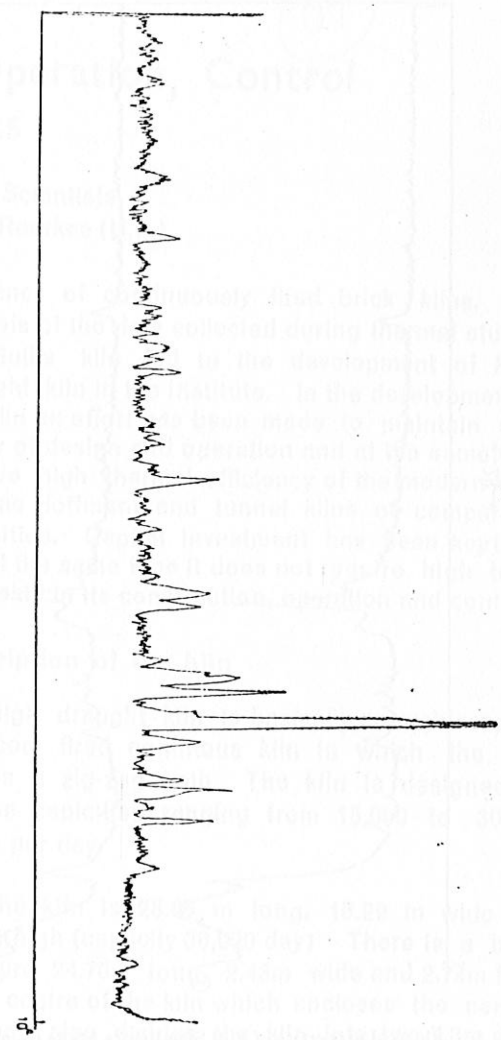

Fig. 4- X ray diffractogram of Indore basalt

Fig. 5 - X -ray diffractograms of Bhopal soil clay fraction (1) untreated (2) treated with glycerol.

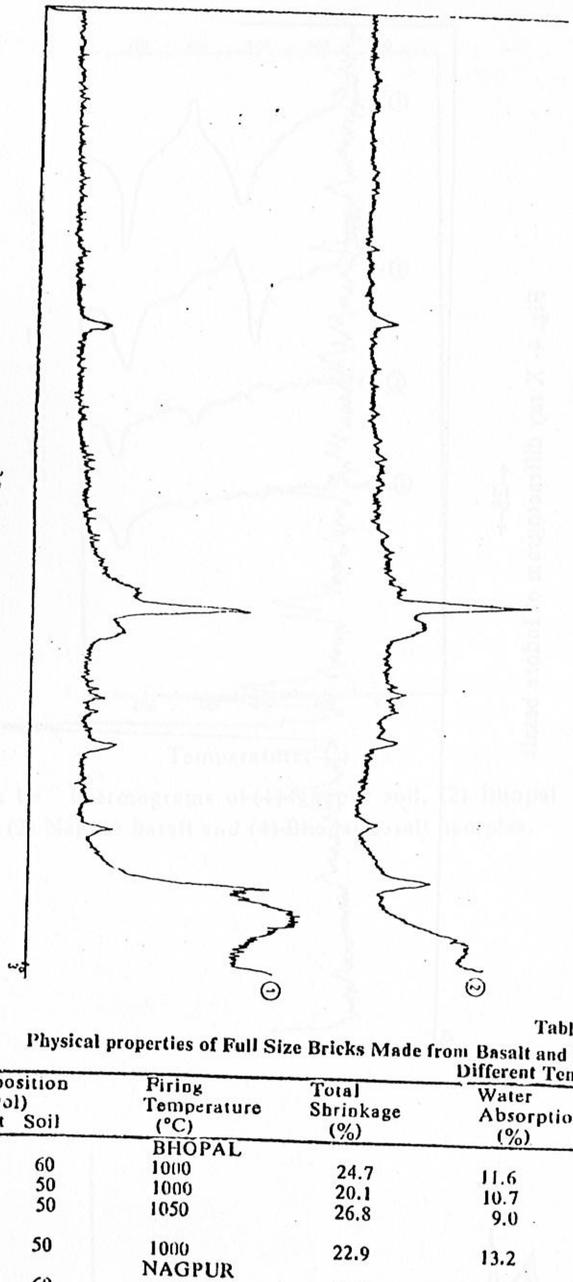

Fig.6 X-Ray Diffractograms of Nagpur soil clay fraction 1 Untreated 2 Treated With glycerol

percent. These results show that by controlling the firing conditions the acid resistance bricks from basalt and black soils can be developed.

The bricks containing 30 percent basalt or grog cracked during drying, so the minimum addition of 40 percent opening material to the soils studied is considered necessary to remove drying cracks. Even 50 percent addition of basalt or grog can be taken up on safe side. The bricks containing equal proportions of basalt and soil and fired at 1000°c showed the compressive strength in the range of 130—175 kg/cm² witn Nagpur, Bhopal or Indore raw materials. The compressive strength of bricks having 50 percent grog and fired at 1000°c showed the compressive strength of 130 kg/cm². The water absorption values of the briquettes containing basalt are lower than those containing grog.

Finally it is concluded that the addition of basalt dust to plastic soils is more advantageous than the use of grog for making building bricks in those areas to overcome the serious problem of drying cracks and the use of basalt dust if available nearby would be quite economical. Engineering bricks of very high compressive strength can also be produced from suitable basalt and clay compositions by firing at high temperature under controlled conditions. The data produced in this paper confirms the common practice on the scientific lines and indicates further scope of the development of basalt ceramics from indigenous raw materials in this country.

Table 10

Physical properties of Full Size Bricks Made from Basalt and Soil Samples from Nagpur, Bhopal and Indore and Fired at Different Temperatures

Composition (by vol) Basalt	Soil	Firing Temperature (°C)	Total Shrinkage (%)	Water Absorption (%)	Bulk Density (gm/cc)	Compressive Strength (kg/cm²)
		BHOPAL				
40	60	1000	24.7	11.6	1.82	150
50	50	1000	20.1	10.7	1.85	175
50	50	1050	26.8	9.0	1.88	205
Grog						
50	50	1000	22.9	13.2	1.80	130
		NAGPUR				
40	60		14.9	12.3	1.79	148
50	50	1000	10.7	11.8	1.83	163
		INDORE				
40	60		20.8	12.5	1.78	110
50	50	1000	17.3	12.0	1.80	130

Acknowledgement

This paper forms part of the research work carried out at the Institute and is published with permission of the Director.

References

1. Experiments in the use of Basalt in Heavy clay products- W. Gilbert and G. Hughes-Clay craft 1966. 39 (5). 156-62.
2. Acid Resistant Basalt - Clay product by Slip Casting process - Elesha Tauber -Common Wealth Scientific and Industrial Research organisation. U. S. 3700, 472, Oct. 24, 1972.
3. Strong Ceramic Tiles Composed of Granular Basalt and Clay - CSIRO British patent 1086, 581, Oct, 11, 1967 (Australian Appl. J. Jan, 8 and April 13, 1964).
4. Abrasion Resistant Fired Tiles - Takeshi, H., Shingeru,U. - Japan 7249,288, 11th Dec, 1972.
5. Ceramic Sintered Mouldings - Burger, A - German offen 2,423, 834, Nov. 1975 (Chemical Abstract 110442 84 (1)., 1972).
6. The Use of the Unifired Soil Classification System by the Bureau of Reclamation -Wagner, A. A. - Proceedings IV International Conference on Soil Mechanics, Foundation Engineering 1957, 1, 125.