Draft

Guidelines for

Management and Handling of Marble Slurry generated from Marble Processing Plants in Rajasthan

Central Pollution Control Board

(Ministry of Environment & Forests)

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Abbreviations

BOD	-	Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand
CPCB	-	Central Pollution Control Board
EC	-	Electrical Conductivity
GW	-	Ground Water
KM	-	Kilometer
MoEF	-	Ministry of Environment & Forests
NHAI	-	National Highway Authority of India
PCC	-	Pollution Control Committee
PVC	-	Polyvinyl Chloride
PWD	-	Public Work Department
RIICO	-	Rajasthan State Industries & Investment Corporation
SPCB	-	State Pollution Control Board
SPM	-	Suspended Particulate Matter
SS	-	Suspended solid
TDS	-	Total Dissolved Solid

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Content

1. Introduction

The word 'marble' is derived from Greek word *mármaron i.e.* "Crystalline rock" or '*Shining stone'*. In terms of geological definition 'it is a metamorphosed limestone produced by re-crystallization under thermal condition and also regional metamorphism.' Marble is a rock resulting from metamorphism of sedimentary carbonate rocks, most commonly limestone or dolomite rock. The purest calcite ($CaCO_3$) marble is white in color. Marble containing hematite (Fe_2O_3) is reddish in color where as limonite ($FeO (OH) \cdot nH_2O$) containing marble is yellow in color. The green color of marble is due to contains of serpentine $(Mg, Fe)_3 Si_2 O_5 (OH)_4$. Marble is defined as a 'minor mineral' in Clause (e) of Section 3 of Mines and Minerals (Development & Regulation) Act, 1957.

Marble is the most preferred stone in India among all dimensional stones because of its pleasant & transparent colors, uniform texture, smooth & shiny polished surface and silky feel. The 'Tajmahal' at Agra & Victoria Memorial Palace at Kolkata are few of the remarkable monuments build of this shining stone 'Marble'. Italy, Turkey, Spain, China & India are the top five dominant countries in terms of marble production. In India, Rajasthan alone accounted for 94% output value followed by Gujarat and Madhya Pradesh. Production value was less than 1% in Odisha, Andhra Pradesh, Jammu & Kashmir and Jharkhand in 2009-10.

Rajasthan is the richest state in the country with regards to marble deposits (1100 Million Tons) both in quality & quantity. The ever increasing popularity of the marbles of Rajasthan, growing demand for finished/unfinished products, discovery of new marble deposits and growing private & public supports have led to a significant growth in Marble Industry of this State. As a result, numbers of marble quarries as well as marble processing units have significant increase mainly during last one decade. Around 3600 marble queries/mines and 1200 marble processing (gangsaws) units and 400 Automatic Tiling Plants (Block cutters) spread all over the 16 Districts of Rajasthan ***(details given at Table No. 01).*** The important regions of marble deposits are Udaipur - Rajsamand - Chittorgarh region, Makrana - Kishangarh region, Banswara - Dungarpur region, Andhi (Jaipur) - Jhiri (Alwar) region and Jaisalmer region.

Most of the quarries in Rajasthan are not mechanized and the quarrying is done using traditional technologies. Only about 350 quarries are fully mechanized using wiresaw/

chainsaw technology. Due to ill equipped mining with respect to mechanization as estimated 60% of marble block comes under mine waste that includes odd blocks of various sizes & shapes, unwanted blocks or rock fragments produced during trimming and shaping of mined out blocks before dispatch to processing units. During processing of marble block on gangsaw, 10% of the mined marble comes under processing waste comprising of small fragment & powder mixed with water. On grinding & polishing 5-7% waste generated comprising fines of marble mixed with grinding & polishing material in water. From un-mechanized mining to processing and processing to polishing in total 70% of the mined marble is waste. Nearly 20% of the total weights of the marble processed results into marble slurry that contents 35-45% water. Every year nearly 5-6 million metric tons marble slurry waste generated through established processing units. The mine & processing waste are dumped on forestland, roadsides, riverbeds, Pasteur lands & agricultural fields. However, Rajasthan State Industries & Investment Corporation (State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan) and marble associations has identified & demarcated the dumping sites than also the unscientific & improper dumping of slurry is in practice. This unscientific & improper dumping of slurry is deteriorating environmental quality by reducing water permeability, soil fertility & increasing the Suspended Particulate Matters (SPM).

This guideline deals with scientific collection & disposal of marble waste along with the gainful utilization of the slurry waste.

2. Marble mining, processing & generation of marble slurry

About 3600 marble quarries are operational in various regions like Makrana (Nagaur), Morwad area, Rajnagar (Rajsamand), Andhi (Jaipur), Salumber, Jaisalmer, Bidasar (Churu) of Rajasthan. Most of the quarries are not mechanized & the quarrying is done using traditional technologies. Only about 350 quarries are fully mechanized using wiresaw/chainsaw technology.

2.1 Marble mining & waste generation

In dimensional stone mining, large-size intact blocks without minor cracks or damages are extracted by means of manual, semi-mechanized & fully mechanized mining machineries ***(Fig. 1).*** The site selection of marble mine is being done in consultation with the mining department. The removal of overburden is generally carried out with heavy earth-moving machinery. In some cases, the weathered zone is removed by

Fig 1. Open cast marble mining

drilling holes by jack-hammers and slim drill machines for the drilling purpose. These holes are charged with light explosives and under controlled blasting methods the over burden material is loosened out. After studying the topography, marble block is marked for removal from the query by manual, semi-mechanized & fully-mechanized means of mining. The details of mining operations are as below:

In manual operation, a line of shallow holes is made and by driving in wedges with feathers by continuous hammering, a fracture is developed along the already drilled holes and the block is made free from all the sides. The block thus freed from the in-situ rock is either pulled by chains or pulley system or is pushed by driving logs, etc.
After the block is toppled, it is again cut and dressed for getting a parallel-piped shape.

In the semi-mechanized operation, jack-hammers, slim drills, line drilling machines are used for drilling holes in a predetermined line. The remaining operation is more or less similar to manual mining except for lifting and pulling where cranes, winches, dozers etc. are used. But in the above mentioned processes, the wastage is high and the size of the blocks recovered is small and seldom free from defects.

In fully mechanized operation, the quarry front cut is made by using slim drill machines, diamond wire saw, quarry master; diamond belt saw machines and chain saw machines. The slim drill machines and quarry masters are used to drill holes through which diamond wire saw is passed and the block is cut by continuous motion of the diamond wire saw. Once the block is cut, it is toppled with the help of hydrobags, pneumatic pillows, air-jacks, etc. The blocks cut this way are of exact sizes with minimum losses. The lifting and loading of blocks are done by Derrick cranes and using various types of loaders.

Marble waste during quarrying by mechanized processes can be estimated at 30% to 40% of the production. The Conventional quarrying techniques of blasting leads to a waste percentage of 60% to 70% and lead to uncontrolled stripping of vegetation cover and subsequent soil erosion. However, since most of the quarries in India are ill equipped as far as mechanization is concerned, the percentage of marble waste, as generated during quarrying of marble blocks can be estimated at 60%. This waste includes odd blocks of various sizes and shapes, unwanted blocks and rock fragments produced during trimming and shaping of mined out blocks before transporting to processing units ***(Fig. 2).***

Fig. 2 Transportation of Marble Blocks

2.2 Processing of marble block & slurry generation

Rajasthan state has more than 95% of marble processors. Important processing centers in the State are Makrana, Kishangarh, Rajsamand, Alwar, Udaipur, Nathdwara and Abu Road, where over 1200 marble processing (gangsaws) units and 400 Automatic Tiling Plants (Block cutters) are established.

The rough and unpolished marble block, firstly received from mines ranges 15-20MT weight which is unloaded in the gantry yard with the help of gantry cranes ***(Fig. 3).*** To remove the non-uniform surface of blocks, they are dressed on dressing machine before shifting to gangsaw machines having 75-125 saws in parallel ***(Fig. 4).*** Each saw is brazed with number of segments called diamond segments. These segments act as teeth and cut block into required thickness. The normal thickness is 15-20 mm. This thickness of segment is approx. 5mm while saw thickness is 3 mm. The blade thickness of the saw is about 5 mm and normally the blocks are cut in 20mm thick sheets. Therefore, out of every 25mm thickness of marble block, 5mm thick block turns into powder on cutting.

Fig. 3 Rough & non-uniform marble blocks received in Gantry yard

During processing of marble block water as coolant is continuously sprinkled on block to reduce the heat generation. The wet dust generated in cutting process is being stored in sedimentation tanks. Due to sedimentation the dust (solid) settles down and the transparent supernatant water again reused for sprinkling over block. The water requirement is fulfilled by processer through water tankers. Thus, about 20-25 % of the marble block processed results into marble slurry. The marble slurry has nearly 35%-45% water content. 5-7% of processed marble block turns into polishing waste on grinding & polishing of the block.

Fig. 4 Processing of Marble Block through Gangsaw machine

3. Water requirement & its management

During processing of marble block continuous water sprinkling is done to reduce the heat generation because of the friction between stone & saws. The supply of water to processors in water scarce state is done through tankers and deep borewells.

About 30% is the waste generation on each marble block processing over gangsaw. Out of which, about 20-25% is marble slurry and 5-10% is of broken edges/slabs. Generally, the wet marble slurry generated during marble processing is diverted to sedimentation tanks to settle the marble dust by gravity on time span ***(Fig. 5).*** The supernatant water is pumped back to sprinkle over the processing block. In this way, continuous recycling of water is practiced. The settled semi-solid slurry is pumped in tankers and transported for disposal. State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan & marble associations has identified slurry disposal sites at Kishangarh, Udaipur, Rajsamand & Chittorgarh. However, dumping of slurry on road side or abandoned land is still in practice.

On an average 20-40 Tons of marble block is processed on a gangsaw in a single day. In the sedimentation tank slurry settling process & recycling of water, daily water loss is nearly about 1000-1500 Ltrs.

Few marble processors have installed vertical settling tanks ***(Fig. 6)*** to sediment the slurry & to recycle the water to processing units. To increase the rate of sedimentation, flocculating & coagulating chemicals are also used. Filter press, is a promising technology to reduce the water percentage of slurry. However, this technology was not adopted by many processors because of the economic issues.

Fig. 5 Sedimentation tanks used for settlement of semi-solid marble slurry

Fig. 6 Vertical settling tanks for sedimentation the marble slurry

4. Characteristics of marble slurry

The color of marble slurry depends on the contains of marble i.e. calcite ($CaCO_3$), hematite (Fe_2O_3), limonite ($FeO(OH) \cdot nH_2O$) and serpentine ($(Mg, Fe)_3 Si_2 O_5 (OH)_4$) gives white, red, yellow and green color of slurry respectively. Marble slurry samples of Kishangarh, Rajsamand, Udaipur, Makrana and Chittorgarh regions studied for physical and chemical characteristics states that in large, the marble slurry on dry is fine powder of mostly Off white color. The dried marble slurry has about 40% particles below 75µm diameter of which about 30% has size less than 25µm size. The particle size distribution ranges from <45 to 300µm. The particle density of slurry ranges from 2.70 to 3.00 gm/cm^3 and the bulk density ranges from 0.9-1.4 gm/cm^3. The loss on ignition ranges from 23 to 35% and moisture is ranges from 5 to 20%.

Makrana marble slurry has calcite as major mineral whereas in the marble of Rajsamand, Udaipur, Chittorgarh and Kishangarh regions dolomite is found as major mineral. The Makrana marble slurry has 39.4-47.4% and 4-8% of CaO & MgO respectively. The dolomite mineral marble slurry of Rajsamand, Udaipur, Chittorgarh and Kishangarh regions has 26.4-47.4% and 15.86-22.10% of CaO & MgO respectively. ***(Details given at Table no. 02 & 03).***

5. Management and handling of marble slurry (Current Practices)

Earlier, the generated marble slurry through marble processing units was being improperly collected & dumped at any abandoned land or near the roadsides. This kind of practice is still going on near the Chittorgarh, Nimbahera, Neemuch & Shahpura (Alwar) areas. However, now-a-days proper marble slurry collection & dumping at identified sites is in practice at many processing areas.

The current statuses of slurry disposal practices are as under:

5.1 Kishangarh

Kishangarh district is having about 523 marble gangsaws and 28 granite cutters in operation. Approximately slurry generation is 5500-6000MT per day. The generated slurry is being transported through tankers (capacity around 4000 litres) to the disposal site notified by Rajasthan State Industrial Development & Investment Corporation Ltd. (State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan). Daily 2000-2200 tankers are engaged in slurry disposal ***(Fig. 7).***

Fig. 7 Marble Slurry dumping at Kishangarh, Ajmer dumping site

Kishangarh Marble Udhyog Vikas Samiti has developed a dumping site (Phase-I) in year 2005-06 in about 322 bigha area of 30-35 feets depth. The decanting wells are also provided and decanted water is recycled to gangsaw units. Dumping site is designed to take care of marble slurry, generated from processing houses with the life of 05 years. Another dumping site has already been developed under Phase-II in 532 bigha area near to earlier dumping site to dump the generated marble slurry ***(Fig. 8).***

Fig. 8 Marble slurry dumping sites (Old & New) at Kishangarh, Ajmer

The Kishangarh Marble Udhyog Vikas Samiti and Kishangarh Marble Association have taken up the steps towards the dumping/disposal of marble slurry. Penalties are being posed on units who are dumping waste marble slabs & slurry anywhere in the town. The broken marble slabs (Krazzy) at dumping site are being collected by the marble chip & tiling units without any cost.

5.2 Makrana

About 421 marble processor, granite cutter, modern slab & tile processing units are operational in this town. Many stone crafting units have also developed. About 939 queries & mines on lease/license are active in marble mining. The processed marble slurry is dumped at unauthorized land near the railway crossing at Manglana. The proper authorization is yet to be awarded by State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan to Sangmarmar Vyapar Mandal & Industrial area Entrepreneur Association, Makrana to develop the dumping site ***(Fig. 9).***

Fig. 9 Marble slurry dumping site near Manglana, Makrana

5.3 Rajsamand

Rajsamand, the district of largest marble deposits has about 250 modern gangsaws, 125 mineral grinders & 20-25 tiling units operational. Marble Gangsaw Association, Rajsamand has identified & developed dumping site in 250 bigha area near to the Nandora village. Marble slurry is also dumped at low-lying area for the purpose of landfilling.

5.4 Udaipur

Udaipur has over 100 Million Tons of marble deposits at around Babarmal, Rikhabdev, Masaron Ki Obri, Darauli, Tidi, Jaspura, Paduna, Manpur and Lohagarh where about 600 to 700 queries/mines are operational. To process, marble mined from these queries or mines, about 135 to 150 gangsaw machines are installed in 100 marble processing units along with 20 to 25 marble tiling plants. Udaipur Marble Processors Association has identified a dumping site at Chitrakoot Nagar near to Khelgaon and regular slurry dumping is done through tankers ***(Fig. 10).*** This 30ft deep dumping site needs to be raised upto 100fts high walls to avoid the problem of slurry overflow during rainy season. Earlier the slurry was used for landfilling the Khelgaon low-lying area.

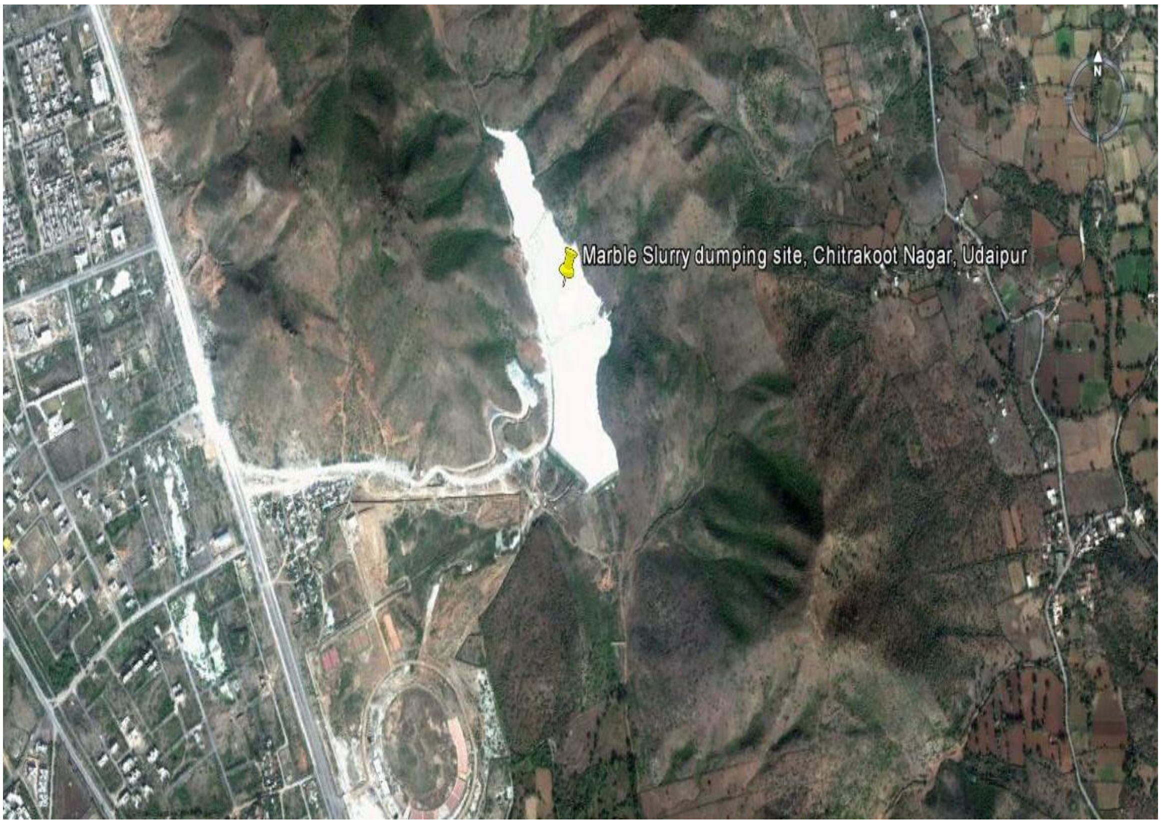

Fig. 10 Marble slurry dumping site at Chitrakoot nagar, Udaipur

5.5 Chittorgarh

Chittorgarh has two marble processing areas one is at Chanderia, Mandalda & another at Azoliya Kheda, Det village. About 100 and 30 to 40 gangsaws are operational at Chanderia & Azoliya Kheda respectively. Marble Association of Chittorgarh has identified dumping site near Det village near Bedach River.

6. Environmental impacts associated with marble slurry dumping

Studies have revealed that improper dumping of marble slurry causes adverse impact on ecology, health and quality of water & air. Reduced porosity & permeability of the topsoil affects the soil fertility and reduces the percolation rate of rain water results in reduced rate of ground water recharging. Fine particles of slurry on drying blew with wind & settle over epidermal layer of crops & plants results in stomata (responsible for plant respiration) blocking. Continuous exposure of marble dust can cause severe respiratory disorders like bronchitis, asthma along with dermal & eye irritation in labors and local population. Deposition of particulate/fugitive dust on roads upto 2-5cm causes emission of particulate matter due to vehicular activities and strong wind currents. Disposing the slurry waste near to water bodies, road side areas can deteriorate the surface & ground water quality by increasing turbidity, suspended solids, calcium and magnesium hardness. The workers working near/on the processing gangsaw machine are getting exposed to continuous noise level of 90-120 dB(A), this high decibel sound exposure can cause annoyance & aggression, hypertension, high stress levels, hearing loss, sleep disturbances.

7. Guidelines for storage, management, handling and disposal of marble slurry

Following guidelines are applicable to the dumping sites which are in operation or closed or proposed to be closed or proposed for lateral expansion as well as for new dumping sites. This guideline also deals with temporary storage of slurry by processing units.

7.1 General guidelines for approval of new/expansion of marble processing unit and temporary storage of slurry in processing unit premises

7.1.1 Requirement of approvals for new or expansion of marble processing unit

i. Marble processing units proposing to install new or additional gangsaw (s) shall obtain Consents under Water (Prevention and Control of Pollution) Act 1974 & Air (Prevention and Control of Pollution) Act 1981 from the concerned State Pollution Control Board (SPCB) or Pollution Control Committee (PCC) prior to the installation and also submit the details along with the Consent application, such as (a) source of water intake, water consumption for different purposes, source of waste water generation & waste water treatment (b) reutilization & disposal arrangements for tread effluent and domestic sewage (c) quantity of slurry & cuttings generated along with the details of dewatering/drying facilities i.e. settling tanks, filter press & platform for drying (d) temporary storage facility (e) slurry reutilization and disposal arrangements (f) unit’s individual action plan (not clubbed with the action plan of Association or any other institution) for gainful utilization of marble slurry (g) details of membership of Association for disposal of slurry at the identified and scientifically developed site by State Industrial & Investment Corporation/District Administration/Competent Authority.

ii. The water consumption in the processing of the marble on one gangsaw shall be in the range of 1-1.5KLD where settling tanks are installed and 2.0 to 3.0 KLD where overhead settling tanks are used. Processing unit shall restrict & minimize its water consumption as above & to measure the same, unit shall install flow measuring devices/meters.

iii. The processing unit shall not be established, operated, expanded, modified or closed without prior approval/ intimation to the SPCB/PCC.

7.1.2 Guidelines for temporary storage of marble slurry within the processing unit

Until the State Industrial & Investment Corporation/District Administration/Competent Authority haven't identified & scientifically developed the dumping site or processing unit yet to obtain membership of Association for dumping the slurry, the individual units shall develop a temporary dumping site within their premises. Following guidelines are applicable:

i. Slurry shall be handled under a covered shed of adequate size (capacity to store waste of one to two years) of impervious storage tanks with proper overflow drainage system. Under no circumstance, slurry shall be stored outside the designated storage area.

ii. While transporting the slurry from the temporary storage area to the identified slurry dumping sites, Unit or Association may take care of 'Zero' spillage through the tankers.

iii. In case of any spillage of marble slurry on public roads while transporting, it is the sole responsibility of the generator for clearing such spillage immediately.

Note: Above guidelines are also applicable to the Units utilizing the marble slurry where there is a necessity for temporary storage of slurry, prior to its use is required.

7.2 Guidelines for location, construction, operation and maintenance of marble slurry dumping site

i. Marble slurry dumping site may be located within the existing marble processing premises or it may be located at isolated locations preferably 01 KM away from any notified habitat area human habitation at suitable location as approved by the

SPCB/PCC and shall be provided with proper approach roads for safe transportation of marble slurry.

ii. The marble slurry dumping site shall not be located on the 100-year flood plain where it will restrict the flow.

iii. Marble slurry dumping site should be located at least at a distance of 1000 meters away from any natural or artificial water bodies and whereas the existing marble dumping site should take adequate measures such that the runoff from the marble slurry dumping site should not be allowed to go into the surface water or any natural or artificial water bodies. SPCB/PCC should monitor the adequate measures made at old dumping sites.

iv. The marble dumping site identified by State Industrial & Investment Corporation/District Administration/Competent Authority should be scientifically developed after the Environment Impact Assessment study.

v. The dumping site shall be designed, constructed, operated & maintained at least for a period of 15 years. The base & side of dumping site should be of 01 meter or thicker with compacted clay lining having hydraulic conductivity, $K \leq 1x\ 10^{-7}$ m/s to eliminate any seepage. The dumping site should also provide proper water decanting system like decanting well or network of perforated PVC pipes at the bottom of site for collection of slurry water.

Conceptual plan for marble slurry dumping site is given at **Fig.11 to 13.** The design of dumping site may be changed according to the site conditions.

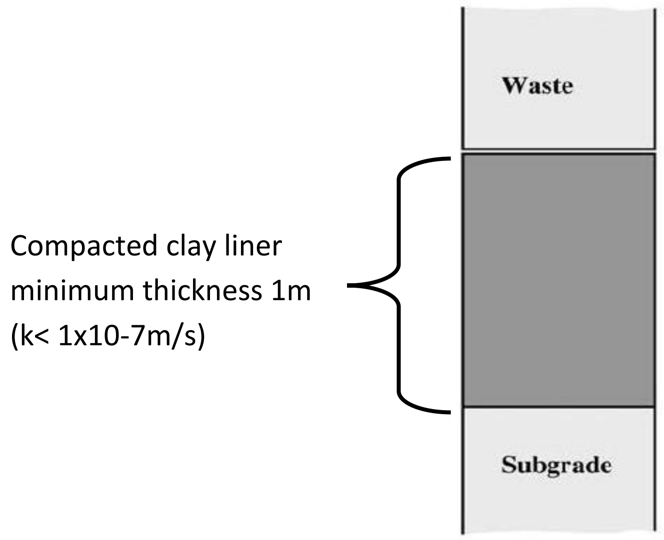

Fig. 11 Suggested liner system for marble slurry dumping site

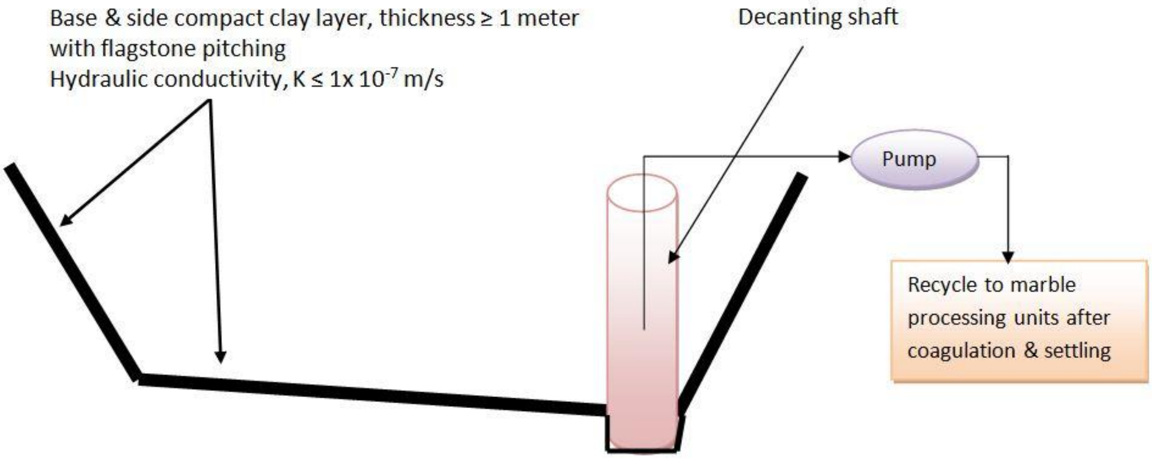

Fig. 12 Cross sectional design for marble slurry dumping site

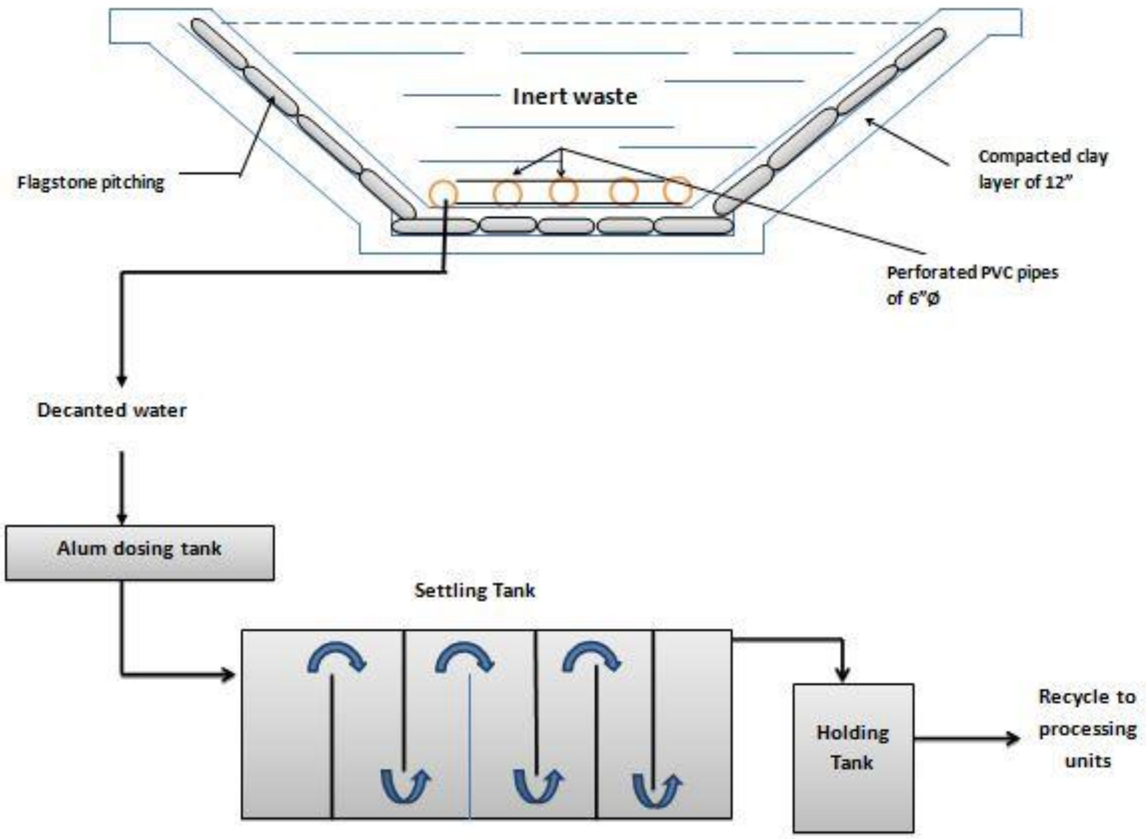

Fig. 13 Marble slurry dumping site and water recycling system design

Note: The conceptual marble slurry dumping site design plan may be changed according to the site conditions.

vi. 10 meters thick green belt of wide leaf species should be developed all around the dumping site to trap the airborne fine particles.

vii. During the operational phase & post-closure maintenance period (at least for 05 years) of the dumping site, it shall be inspected at least once in a month as a part of the maintenance and contingency plan and suitable remedial measures shall be taken to have no impact on the environment along with this suitable measures shall be taken to avoid fugitive emissions due to wind erosion of dry marble slurry from the dumping site. To ensure the proper operation & maintenance of slurry dumping site including closure and post monitoring, an escrow fund is to be generated from all members of marble associations & State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan and the fund shall be kept reserved by the private limited company constituted comprising members of local marble association, district administration, State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan and SPCB.

The contribution in escrow fund shall be decided in general body meeting of private limited company formed for the purpose as mentioned above.

viii. Suggested temporary closing system for existing dump sites is given in **Fig. 14.** The waste stored in dump site shall be utilized for other beneficial uses as described in **Point no.** 8 (Guidelines for beneficial uses of marble slurry).

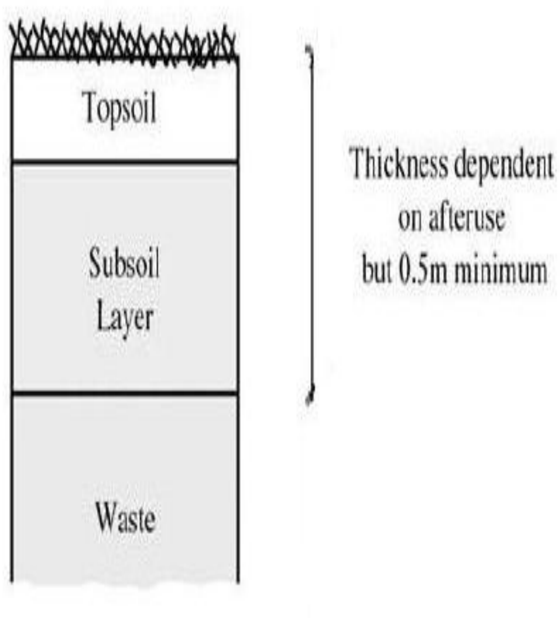

Fig. 14 System for Closure of dumping site

ix. The dumping site should be guarded round the clock. Daily records of quantity of slurry received/dumped & lifted for utilization should be maintained and annual report should be submitted to SPCB/PCC by 30th June of every year.

8. Guidelines for beneficial uses of marble slurry

As far as possible, the marble processing units should put efforts to utilize the generated marble slurry for beneficial purpose such as raw mix component and/or additive for manufacturing of Ordinary Portland Cement, as a substitute of soil in road construction, as binder in non-load bearing structures, in brick manufacturing, in artifacts manufacturing, as a filler material in minerals (feldspar, soda & quartz) grinding, recovery of calcium nitrate as fertilizer, in Polyvinyl Chloride (PVC) manufacturing etc. For utilization of the marble slurry following guidelines are required to be followed:

1) All the Ordinary Portland cement manufacturing units shall utilize about 10-12% marble slurry of any marble clusters as per the recommendations of National Council for Cement & Building materials (NCBM), New Delhi. The moisture percentage needs to be reduced as per cement plant requirements. Technical report of NCBM is enclosed as **annexure-I (a).**

2) All the Ordinary Portland Cement manufacturer shall replace OPC clinker with 3 to 5% of marble slurry during clinker grinding as a performance enhancer after reduction in moisture to the requirement of cement manufacturers and Indian Standards IS: 8112:1989 as amended. Technical report of NCBM is enclosed as **annexure-I (b).**

   To utilize the marble slurry waste in Ordinary Portland Cement manufacturing plants as above, the nearby marble associations need to associate with cement industries with mutual agreement having business conditions including condition of transportation cost sharing on 50% basis by both the parties and the rates of transportation shall be decided in consultation with SPCB/PCC.

3) In road pavement, construction of sub-grade layer shall be done by replacing 20-35% of in-situ soil by marble slurry by following the Public Work Department (PWD) & National Highway Authority of India (NHAI) road construction

specifications. Outcome of technical research initiatives of Central Road Research Institute, New Delhi is enclosed as **annexure-II.**

4) Marble slurry as binder: sand ratio (1:3) shall be utilized as building material as per IS: 3466-1988 specifications. The marble slurry as low cost binder (Indian patent no. 189030) shall be utilized for non-load bearing structures as per Public Work Department (PWD) specifications. Technical work carried out by Shri Sampat Lal Surana on “Binder made from Marble Slurry: a solution to the problem” is enclosed as **annexure-III** may also be referred.

5) As far as possible, mineral (feldspar, soda & quartz) grinding units shall utilize 15-20% of marble slurry as a filler material as per the mineral specifications.

6) Coal/pet coke based Thermal Power Plants may also explore the possibility of utilization of marble slurry as desulphurizing material as well as production of gypsum as by-product. Zinc smelter may also explore the possibility of utilizing marble slurry waste along with their process Jarosite waste in production of synthetic gypsum ***(details of the same given at Table No. 04).***

7) Iron & steel manufacturing industries may also explore the possibility of use of marble slurry as flux or reducer considering percentage of SiO_2 & loss on Ignition.

8) Any entrepreneur who wishes to manufacture Calcium Nitrate fertilizer from marble slurry waste may approach the concerned State Pollution Control Board (SPCB)/Pollution Control Committee (PCC) for obtaining consents as required for establishment of such recycling industry. SPCB/PCC shall consider the application on priority basis.

$$CaCO_3\ (s) + 2HNO_3\ (aq) \text{ -------->}\ Ca(NO_3)_2\ (aq) + H_2O\ (l) + CO_2\ (g)$$

9) A huge quantity of marble & its slurry shall be utilized in artifacts, chips and tiles manufacturing also shall be utilized in brick manufacturing as approved by PWD as mentioned in Chapter G3 Materials for building work Sub section 3.10 ***marble waste slurry bricks*** dated 01-05-1998.

9. Time schedule for remediation/utilization of slurry of existing dumping sites

S.No.	Action	Time line for the action to be initiated
1.	Constitution of private limited company of representatives of various stakeholder (marble association, State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan, district administration, cement industries & SPCB) Creation of ESCROW FUND through members of marble associations and State Industrial Infrastructure Development Agency i.e. RIICO for Rajasthan	Before December, 2013 Before December, 2014
2.	Execution of mutual agreement between private limited company, cement industries and other beneficiary units for transportation & cost sharing on 50% basis	From December, 2013 & onwards
3.	State PWD may specify the use of marble slurry as a construction material for non-load bearing structures in their Schedule of Rate (SOR) of material and tender documents State PWD & NHAI may incorporate the terms & conditions to use marble slurry in road pavement, construction of sub-grade layer by replacing 20-35% of in-situ soil in their tender documents	Before June, 2014
4.	**Dumping sites:** a. Survey, monitoring & assessment of existing site by SPCB & State Industrial Infrastructure Development Agency i.e. RIICO For Rajasthan	Before December, 2013
	b. Identification of defaulters/units practicing unauthorized dumping of slurry & appropriate legal action against the same by SPCB/PCC	Before December, 2013
	c. Remedial measure to be taken for health safety & prevention of slurry overflow/ environmental damages	Before December, 2014
	d. Temporary closing of exhausted dumping site	Before June, 2014
	e. Identification & development of new dumping sites	Before December, 2014

10. Monitoring protocol for assessment of environmental impacts in and around the marble slurry dumping site

The decanted/percolated water of marble slurry (25-30% water content) dumps may cause ground water pollution whereas airborne fine particles of dried slurry may increase particulate matters in Ambient Air which resulted deposition of dust over leaves of plants/flora and disturb the overall environmental quality of surrounding area. Therefore, regular air and water quality monitoring shall be conducted by private limited company of Marble Association / stakeholders in consultation with SPCB/PCC. Continuous efforts shall be made to resolve the local environmental issues.

Monitoring Protocol

10.1 Ambient air quality monitoring

i. **Number of monitoring stations:** Three air quality monitoring stations at 120^o angle covering upwind & downwind direction should be installed around the marble slurry dumping site (or within the industrial cluster). Location of the air quality monitoring stations should be fixed in consultation with the State Pollution Control Board (SPCB)/ Pollution Control Committee (PCC).

ii. **Parameters to be monitored and frequency of ambient air quality monitoring:** Parameters stipulated in the Consent under Air (Prevention and Control of Pollution) Act, 1981 should be monitored to know the status of ambient air quality in and around the marble slurry dumping site (s) or within the industrial cluster to take preventive measures. Ambient Air Quality around the marble slurry dumping site(s) & industrial cluster should be monitored monthly for Particulate Matter (PM_{10} & $PM_{2.5}$) on 24 hourly basis.

10.2 Ground water (GW) monitoring

It is recommended to monitor ground water characteristics at least *once in a quarter* around the marble slurry dumping site providing piezometric holes around the site.

(i) **Parameters to be analysed:** The ground water samples should be analysed for pH, Conductivity, Suspended Solids (SS), Turbidity, Total Hardness & Total Alkalinity in addition to other parameters as prescribed by SPCB/PCC in the water consent letter.

(ii) **Sampling locations:** The ground water samples shall be collected at least up to a radial distance of 1.0 KM from the dumping site. If no open wells or tube wells are available within a radial distance of 1 KM, provision of at least four monitoring wells (piezometric holes) around the dumping site (i.e. one on up gradient of the ground water flow and other three on the down gradient side of the ground water flow) at least up to 'shallow water bore well' depth shall be made. Depending upon the situation, if required, the monitoring wells till second aquifer should also be extended in consultation with the SPCB/PCC. The directions of the ground water flow have to be established in consultation with the State Ground Water Board or any other approved authority. The ground water flow direction is required to be ascertained regularly at least once in a three years so as to know any changes in the flow of directions of ground water due to any changes in the local conditions such as excess withdrawal of ground water.

10.3 Surface water monitoring

Monitoring of surface water (pond/lake/river) at upstream and downstream is necessary at least twice in a year (i.e. pre-monsoon and post-monsoon). It is recommended that the surface water samples should be analysed for pH, EC, Turbidity, SS, TDS, BOD, COD, Total Alkalinity and Total hardness.

11. References

i. "Status report on commercial utilization of marble slurry in Rajasthan", prepared by MSME-Development Institute, Ministry of Micro, Small & Medium Enterprises, Jaipur (Rajasthan)

ii. "Utilization of marble slurry as raw mix component and/or additive for the manufacture of Ordinary Portland Cement" prepared by National Council for Cement and Building Materials, New Delhi year 2007.

iii. Research report on Binder made from Marble Slurry: a solution to the problem prepared by Shri Sampat Lal Surana, Mechanical Engineer, Jaipur (Rajasthan).

iv. *A K Misra et. al. (2010),* 'A new technology of marble slurry waste utilization in roads'. *Journal of Scientific & Industrial Research* Vol. 69, page no. 67-72.

v. 'Marble' (advance release) Indian Minerals Yearbook 2011 (Part-II), 50th edition, Ministry of Mines, Indian Bureau of Mines.

vi. *Fakher J. Aukour* (2009), 'Incorporation of Marble Sludge in Industrial Building Eco-blocks or Cement Bricks Formulation'. *Jordan Journal of Civil Engineering*, Volume 3 (1), 58-65

Table No. 01 Marble processing units in Rajasthan (As on 2009-10)

Name of District	No. of Gangsaws						No. of Tiling plants			
	Upto 40	41-59	60-80	Above 80	Total	No. of close units	No. of tiling block cutters	No. of units closed	No. of single wheel cutter	No. of closed cutters
Alwar	2	-	18	-	20	3	2	-	-	-
Abu Road	-	-	16	-	16	3	1	-	1	-
Banswara	5	-	8	-	13	-	8	-	100	-
Chittorgarh	4	-	85	-	89	-	6	-	-	-
Dungarpur	-	-	5	-	5	-	-	-	5	-
Jaipur	2	5	39	-	46	4	17	5	-	-
Kishangarh	7	24	179	2	212	3	1	-	3	-
Makrana	24	100	200	-	324	25	4	2	37	-
Rajsamand	29	-	158	-	187	-	5	5	177	18
Udaipur	5	40	50	-	95	20	10	5	32	2
Total	**78**	**169**	**758**	**2**	**1007**	**58**	**54**	**17**	**355**	**20**

Source: "Status report on commercial utilization of marble slurry in Rajasthan", MSME-Development Institute, Ministry of Micro, Small & Medium Enterprises, Jaipur (Rajasthan)

Table No. 02 Physical characteristics of Marble slurry

Characteristics	Properties
Form	Fine powder
Color	Off white
Shape	Angular
Particle Size (μm)	<45-300
Particle Density (gm/cm^3)	2.70-3.00
Bulk Density (gm/cm^3)	0.9-1.4
Loss on Ignition	23-35%
Moisture (%)	5-20%
Mineralogy	Calcitic & Dolomitic lime

Source: M/s ACC Cement, Lakheri, Kota and NCBM, New Delhi

Table No. 03 Chemical Characteristics of Marble slurry

Constituents	Makrana	Kishangarh	Rajsamand	Udaipur	Chittorgarh
SiO_2%	4.2-10.2	4.98-8.42	6.80-10.24	8.5-11.2	13.64
Al_2O_3%	0.35-1.64	0.52-0.88	0.40-1.0	0.52-1.10	1.20
Fe_2O_3%	0.44-0.92	0.4-0.6	0.5-1.1	0.40-0.94	0.92
CaO%	39.4-47.4	29.6-44.0	28.4-42.0	26.4-40.2	30.88
MgO%	4-8.0	18.0-22.10	16.2-21.8	17.4-21.8	15.86
Moisture%	7-22	10-19	8-21	8-18	25.0

Source: M/s ACC Cement, Lakheri, Kota and NCBM, New Delhi

Table No. 04 Comparative composition of Marble slurry waste & Zinc smelter, Jarosite waste

S. No	Constituents %	Marble slurry	Jarosite
1	CaO	20-40	1.31-1.71
2	SiO_2	15-30	5.42-6.26
3	Al_2O_3	1-2	4.46-6.94
4	Fe_2O_3	2-5	32.36-37.58
5	MgO	20-30	0.1-0.15
6	SO_3	1.51-1.6	29-31
7	Na_2O	0.2-0.5	2.82-3.18
8	K_2O	0.1-0.3	0.31-0.37
9	IR	6-7	3.82-4.55
10	LOI	23-35	32-35
11	ZnO	--	2.5-3.5
12	PbO	--	3.0-4.0

Source: M/s Hindustan Zinc Limited, Chanderia

Annexure – I (a) & (b)

DRAFT REPORT

(Chittorgarh)

UTILIZATION OF MARBLE SLURRY AS RAW MIX COMPONENT AND/OR ADDITIVE FOR THE MANUFACTURE OF ORDINARY PORTLAND CEMENT

FOR

RAJASTHAN STATE POLLUTION CONTROL BOARD

JAIPUR (RAJASTHAN)

CRT-SP-A530
MARCH 2007

NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS

NEW DELHI

BIRLA CEMENT WORKS

CHANDERIA

CHITTORGARH
MARBLE SLURRY
CLUSTER

CONTENTS

RECOMMENDATIONS

1. Based on the laboratory investigations, raw mix **RM-1** with following details provided below is optimized and recommended for the manufacture of ordinary Portland cement utilizing **12.36 percent marble slurry from Chittorgarh marble slurry cluster for M/s Birla Cement Works, Chittorgarh.**

Raw Materials Proportioning		**Moduli Values of Clinker**	
Limestone	: 81.52%	LSF	: 0.93
Marble slurry	: 12.36%	SM	: 2.00
Red ochre	: 5.74%	AM	: 1.02
Laterite	: 0.39%	Liquid content (%)	: 31.66
Ash absorption in clinker	: 2.00%		

Clinkerization Temperature: 1450°C with retention time of 20 minutes

2. Investigations on cement samples prepared with OPC plant clinker and 3 and 5 percent marble slurry sample from Chittorgarh cluster indicated improvement in compressive strength characteristics of cement.

1.0 INTRODUCTION

There are about 4000 marble mines and about 2200 marble processing units spreaded in the area of over 16 sectors in Rajasthan. While cutting of marble blocks by gang saws, water is used as a coolant. The marble powder flows along with the water as marble slurry. Nearly 20 percent of the total weight of the marble processed results into marble slurry. The marble slurry has nearly 35-45 percent water contents. Presently the amount of marble slurry generated in Rajasthan every year is about 1.0 million tonnes on dry basis. The dumping of the marble slurry in the vicinity of marble industry created various problems relating to fertility of soil, air born diseases and environmental pollution.

M/s Rajasthan State Pollution Control Board (RPCB), Jaipur (Rajasthan) approached National Council for Cement and Building Materials (NCB) for undertaking the study on technical feasibility of utilization of marble slurry as a raw material for the manufacture of ordinary Portland cement. NCB agreed to take up the study with the following scope of work.

1.1 SCOPE OF WORK

1. Visit of NCB team for discussions with the representatives of marble manufacturing association, cement units and concerned Regional Officer, RPCB for collection of relevant data and representative samples of marble slurry from following six sites/ clusters.

Site / Cluster	Associated Cement Industries
Kishangarh	Shree Cement, Beawar
Chittorgarh	Birla Cement Works, Chanderia
Rajsamand	J K Cement Works, Nimbehera
Udaipur	Binani Cement Limited, Sirohi Road
Abu Road	J K Lakshmi Cement Limited, Abu Road
Makrana	Ambuja Cement Rajasthan Cement, Rabariawas, Pali

2. Collection of the representative samples of other raw materials viz. limestone, clay, laterite, bauxite, red ochre, mill scale and mineral gypsum etc required from above six cement plants.
3. Physico-chemical and mineralogical characterization of samples collected at 1 & 2 above.
4. Designing of different raw mixes using marble slurry as a raw mix component.
5. Burnability studies of above raw mix designed.
6. Characterization and evaluation of the clinker samples prepared in burnability studies.

7. Optimization of raw mix design in respect of various clusters of marble slurry and cement plants in reference.

8. Preparation of bulk clinker from the optimized raw mix.

9. Preparation of OPC from the above bulk clinker and evaluation of performance for its conformity to relevant Indian Standard Specification.

10. Preparation of cement samples using plant clinker and marble slurry of different clusters and their performance evaluation.

11. To work out techno economic viability based on data provided by the marble slurry generating units and cement plants.

12. Report covering 1-11 above and suggestion/ recommendation for implementation of the above study out come.

2.0 COLLECTION OF MARBLE SLURRY AND OTHER RAW MATERIALS

NCB team consisting of Sh. P S Sharma. Group Manager (Waste utilization) visited the marble cluster area of Chittorgarh on 21 July 2006. Discussions were held with Sh. Veer Singh, Regional Officer, RSPCB – Bhilwara Division and Sh. Bhagchand Mundra, President of Marble Association, Chittorgarh on various aspects Viz. generation and spread of marble units in the area, disposal systems employed at disposal site etc.

Samples of marble slurry were collected in the presence of Sh. Veer Singh and Sh. Bhagchand Mundra as per the sampling scheme provided by NCB team from different locations at the marble slurry disposal area and a representative sample of the marble slurry (weighing about 25 to 30 Kgs.) was prepared. The collected sample was brought to NCB for the investigation.

Other raw materials to be used in the present investigation were arranged from M/s Birla Cement works, Chanderia (Chittorgarh) located in the vicinity of chittorgarh marble slurry cluster as identified in the scope of the work. The raw materials such as limestone, laterite, red ochre, clinker, fine coal and gypsum being used by M/s Birla cement works, Chanderia (Chittorgarh) in the manufacture of cement.

3.0 PREPARATION OF MARBLE SLURRY AND OTHER RAW MATERIAL SAMPLES

3.1 Marble Slurry

The sample of the marble slurry (about 25 Kgs.) collected from Chittorgarh marble slurry cluster was designated as MS-CH and found to contain moisture content of 25.0 percent. The sample was dried at temperature of 105 ± 5^0C in the electric oven. The dried sample was homogenized to obtain a representative sample of marble slurry. The representative sample of marble slurry was prepared by quartering and coning procedure and subjected to chemical and mineralogical characterization.

3.2 Other Raw Materials

The other raw materials such as limestone, laterile, red ochre, clinker, fine coal and gypsum were ground to pass through 100-mesh sieve. The representative samples of these raw materials were prepared by quartering and coning procedure and subjected to chemical and mineralogical characterization. The results are given in the following sections.

4.0 CHARACTERZATION AND EVALUATION OF RAW MATERIALS

4.1 Marble Slurry (MS-CH)

The physical, chemical and mineralogical characterization of representative sample of marble slurry was carried out and the results are discussed below.

Particle Size Distribution

The particle size distribution (PSD) of marble slurry (MS-CH) is given in Table 1. The finer fraction (<10.00 micron) in marble slurry sample is found to be in the range of 50.66 percent indicating that the sample is very fine in nature.

TABLE 1: PARTICLE SIZE DISRIBUTION OF MARBLE SLURRY

S.No.	Diameter (mμ) Undersize	Cumulative Percent
1.	0.30	1.92
2.	0.50	4.35
3.	0.70	6.00
4.	1.00	8.17
5.	1.40	10.88
6.	2.00	15.79
7.	2.60	20.34
8.	3.20	24.39
9.	4.00	29.04
10.	5.00	33.84
11.	6.00	37.94
12..	8.00	44.97
13.	10.00	50.66
15.	15.00	61.09
16.	20.00	68.66
17.	25.00	75.22
19.	36.00	88.14
20.	45.00	94.94
21.	56.00	98.87
22.	63.00	99.71
23.	90.00	100.00

Chemical Characteristics

Chemical analysis of representative sample of marble slurry indicated the presence of 13.64, 30.88, 15.86, 1.20 and 0.92 percent SiO_2, CaO, MgO, Al_2O_3 and Fe_2O_3 respectively. Apart from the five major oxide constituents, the slurry sample also indicated the presence of 0.42, 0.76 and 0.41 percent SO_3, Na_2O and K_2O as evident from Table 2.

TABLE 2: CHEMICAL ANALYSIS OF MARBLE SLURRY (MS-CH) SAMPLE

Sl. No.	Constituents Determined	Percent
1	LOI	36.04
2	SiO_2	13.64
3	Fe_2O_3	0.92
4	Al_2O_3	1.20
5	CaO	30.88
6	MgO	15.86
7	SO_3	0.42
8	Na_2O	0.76
9	K_2O	0.41

X-ray Diffraction Analysis

X-ray diffraction analysis of marble slurry sample indicated the presence of dolomite as major mineral phase along with calcite. Other mineral phases α-quartz, albite and cordierite were present in small amount as shown in Fig 1.

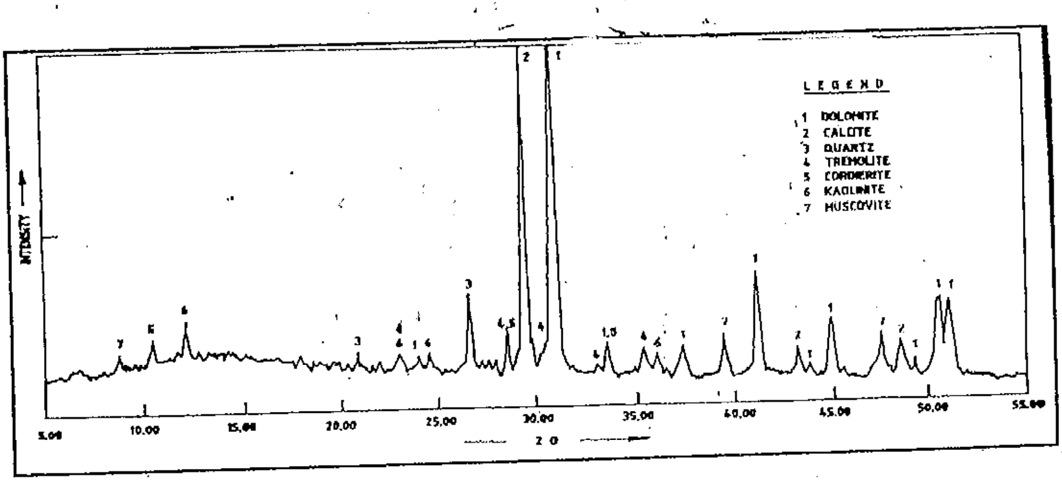

Fig.1: X-ray Diffractogram of Marble Slurry Sample

4.2 Limestone (LS-BI)

Chemical Characteristics

Chemical analysis of limestone sample indicated the presence of 45.98, 11.93, 2.14 and 1.02 percent CaO, SiO_2, Al_2O_3 and MgO respectively. The sample was found to be suitable for the manufacture of ordinary Portland cement (OPC). Chemical analysis of the sample is given in Table 3.

Mineralogical Characteristics

The X-ray diffractogram for limestone sample is shown in Fig. 2. Calcite is found to be the major mineral phase along with α-quartz in small amount.

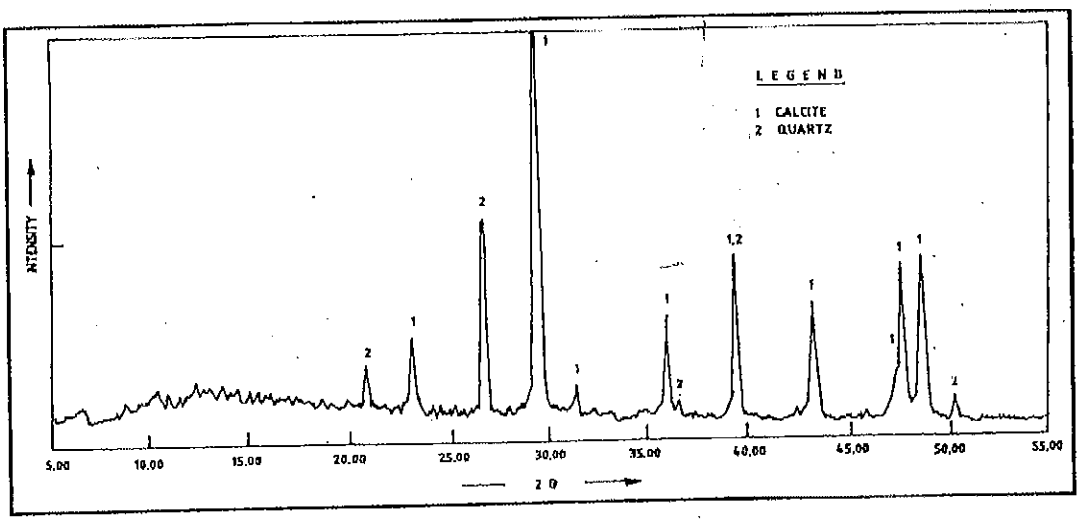

Fig.2: X-ray Diffractogram of Limestone Sample (LS-BI)

4.3 Laterite (LT-BI)

Chemical Characteristics

The chemical analysis of Laterite indicated the presence of 39.92, 21.19, 16.20 and 4.35 percent Fe_2O_3, SiO_2, Al_2O_3 and CaO respectively. The sample is found to be suitable as an additive for the manufacture of ordinary Portland cement (OPC). Chemical analysis of the sample is provided in Table 3.

Mineralogical Characteristics

The X-ray diffractogram of laterite sample indicated the presence of goethite as major mineral phase and hematite, calcite and kaolinite as minor mineral phases as shown in Fig 3.

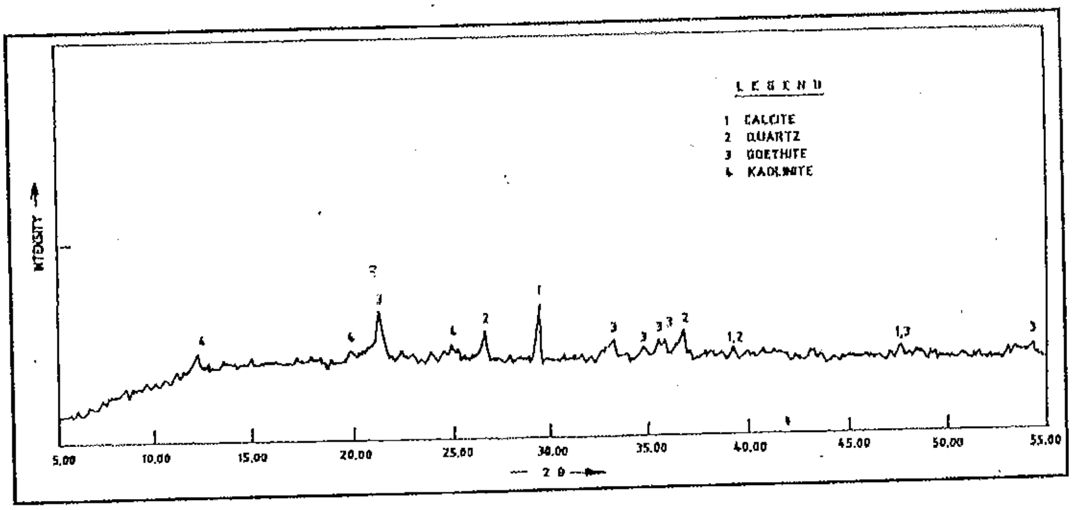

Fig.3: X-ray Diffractogram of Latrite Sample

4.4 Red Ochre (RO-BI)

Chemical Characteristics

Chemical analysis of red ochre indicated the presence of 38.52, 22.26, 21.93 and 0.88 percent Fe_2O_3, SiO_2, Al_2O_3 and CaO respectively. The sample is found to be suitable as an additive for the manufacture of ordinary Portland cement (OPC). Chemical analysis of the sample is given in Table 3.

Mineralogical Characteristics

The X-ray diffraction study of red ochre sample indicated hematite, kaolinite and gibbsite are the mineral phases present in the sample as shown in Fig 4.

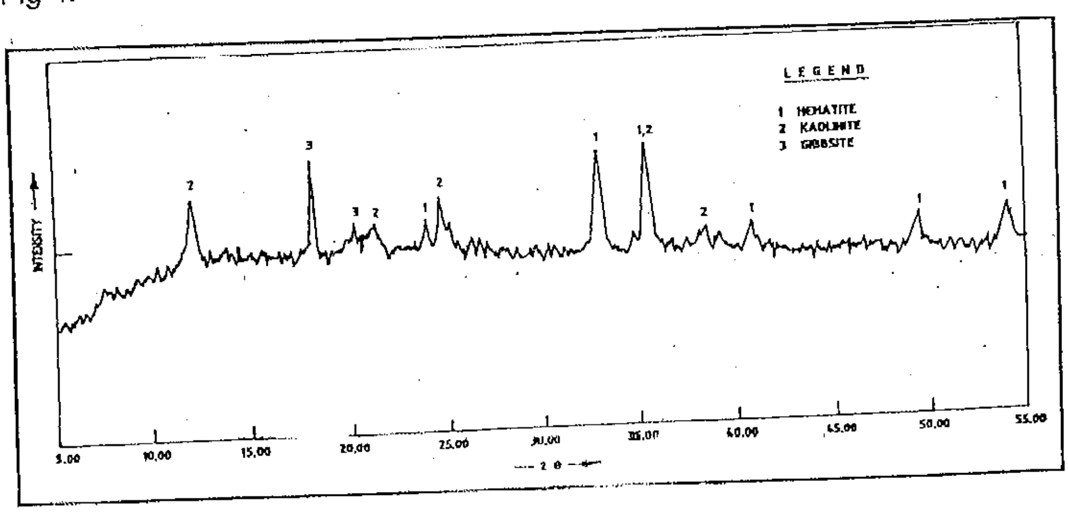

Fig 4: X-ray Diffractogram of Red Ochre Sample

Table 3: Chemical Analysis of Raw Materials

S. No.	Oxide constituents	Limestone	Laterite	Red ochre	Coal ash	Gypsum	Clinker [c]
		Percent					
1.	LOI	36.25	14.03	10.22	3.43	14.52 [a]	1.76
2.	SiO_2	11.93	21.19	22.26	55.59	23.81[b]	21.76
3.	Fe_2O_3	0.96	39.92	38.52	6.93	0.80	5.36
4.	Al_2O_3	2.14	16.20	21.93	15.16	0.48	4.82
5.	CaO	45.98	4.35	0.88	9.11	26.26	61.90
6.	MgO	1.02	Traces	0.09	0.84	0.26	1.77
7.	SO_3	NIL	NIL	NIL	7.31	32.25	0.89
8.	Na_2O	0.32	0.37	0.40	0.35	0.09	0.49
9.	K_2O	0.39	0.12	0.03	1.18	0.05	0.58

a: Combined water,b:SiO_2+IR and c: Insoluble residue:0.30 & free lime: 0.60 percent

4.5 Gypsum (GYP-BI)

Chemical Characteristics

Gypsum sample was analyzed for its oxide constituents and the purity of gypsum, based on SO_3 content has been found to be 69.34 percent. The sample is considered suitable for the manufacture of cement.

Mineralogical Characteristics

X-ray diffractogram recorded for gypsum sample is presented in Fig. 5. Gypsum was the major mineral and calcite, α-quartz and albite were the minor mineral phases present in the sample.

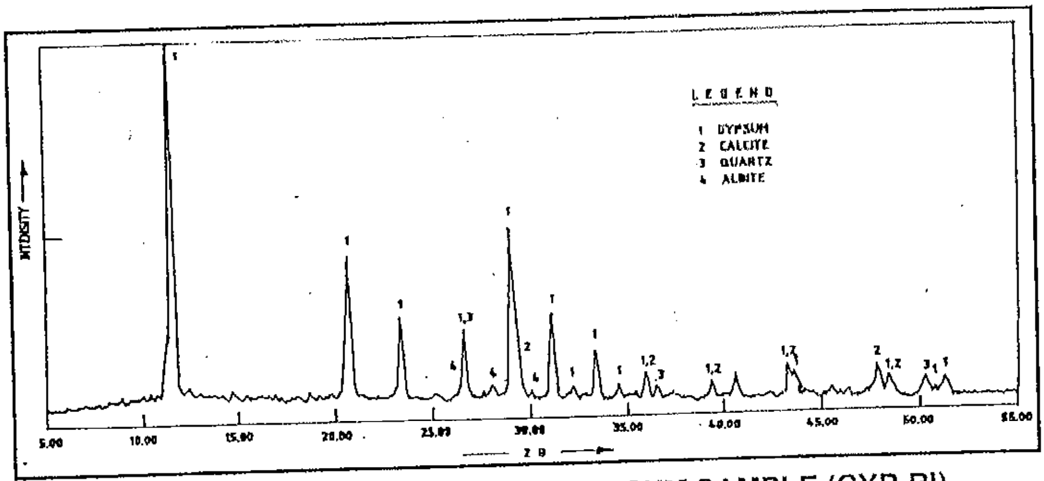

FIG. 5: X-RAY DIFFRACTOGRAM OF GYPSUM SAMPLE (GYP-BI)

4.6 Clinker (CL-BI)

Chemical Characteristics

The chemical analysis of the clinker sample indicated the presence of 21.76, 61.90 and 4.82 percent of SiO_2, CaO and Al_2O_3 respectively. Presence of 1.77 percent MgO, 5.36 percent Fe_2O_3 and 0.60 percent free lime was also detected as given in Table 3. The phase composition calculated by Bogue's formulae indicated the presence of 44.09 and 29.13 percent C_3S and C_2S respectively, indicating good quality of clinker.

Mineralogical Characteristics

The X-ray diffraction study of clinker sample indicated formation of well developed OPC clinker phases with predominance of 45 percent alite, 24 percent belite, 5 percent C_3A and 15 percent C_4AF as indicated in fig.6

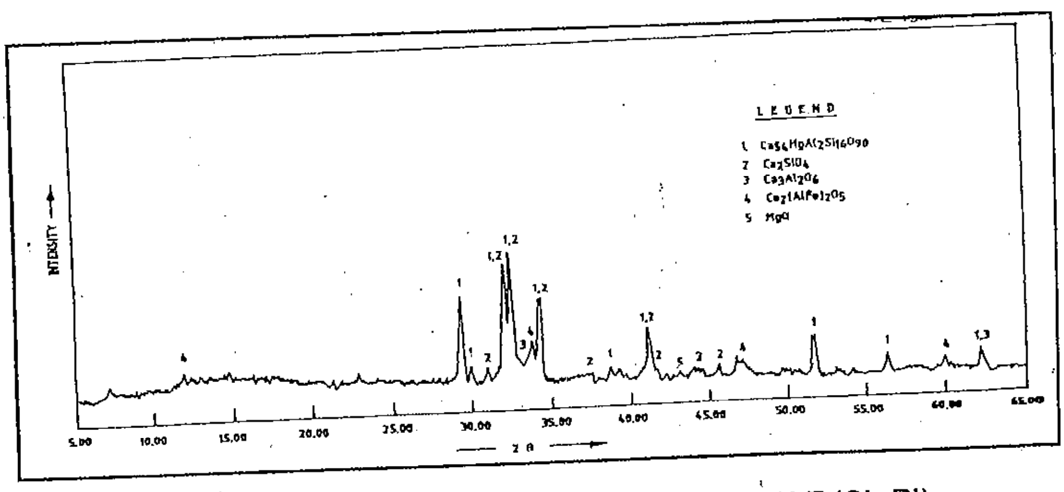

FIG. 6: X-RAY DIFFRACTOGRAM OF CLINKER SAMPLE (CL-BI)

4.7 Coal (Coal–BI)

Chemical Characteristics

The proximate analysis of the coal sample as given in Table 4 indicated the presence of 20.42 percent ash content and 19.44 percent volatile matter with 4.63 percent of moisture content.

The ash prepared from the above coal was subjected to chemical analysis and the results are given in Table 3. Chemical analysis indicated the presence of 55.59 percent SiO_2, 15.16 percent Al_2O_3, 9.11 percent CaO and 7.31 percent SO_3.

Table 4: Proximate Analysis of Coal Sample (Coal-BI)

Sl. No	Characteristics	Results
1	Ash Content (%)	20.42
2	Moisture Content (%)	4.63
3	Volatile Matter (%)	19.44
4	Fixed Carbon (%)	55.51
5	Calorific Value (kcal/kg)	5751

The above results of chemical and mineralogical characterization indicated that these raw materials are suitable for the manufacture of cement.

5.0 UTILIZATION OF MARBLE SLURRY (MS-CH) IN THE MANUFACTURE OF ORDINARY PORTLAND CEMENT (OPC)

The chemical and mineralogical investigation of the marble slurry sample from Chittorgarh cluster indicated the suitability of slurry sample as a raw mix component for the manufacture of ordinary Portland cement (OPC).

5.1 Raw Mix Design

Four raw mixes (RM-1 to RM-4) were designed using limestone, marble slurry, red ochre and laterite samples keeping in view of the maximum utilization of marble slurry. The coal ash absorption level was kept at 2.0 percent in all the designed raw mixes. The raw materials proportioning was given in Table 5 and the oxide constituents of designed raw mixes, moduli values and other clinker parameters were listed in Tables 6 to 9.

Table 5: Various Raw Mix Designs Prepared

Raw Mix No	LS-BI	MS-CH	RO - BI	LAT - BI	Coal ash absorption
	Percent				
RM-1	81.52	12.36	5.74	0.39	2.0
RM-2	79.28	14.49	5.43	0.80	2.0
RM-3	76.21	18.59	4.43	0.76	2.0
RM-4	75.59	19.08	2.87	2.46	2.0

Table 6: Design Parameters of Raw Mix RM-1

Raw Materials	LS-BI	MS-CH	RO - BI		LAT - BI		Coal ash absorption	
Proportion (%)	81.52	12.36	5.74		0.39		2.0	
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Raw Mix	34.64	12.77	3.26	3.21	41.36	2.80	0.39	0.39
Clinker	--	20.26	5.03	5.12	62.21	4.21	0.59	0.59
Modulii Values	LSF		SM		AM		Liquid content (%)	
Raw Mix	0.98		1.97		0.99		31.66	
Clinker	0.93		2.00		1.02			
Potential Phase Composition (%)	C_3S		C_2S		C_3A		C_4AF	
	57.65		14.63		5.06		15.24	

Table 7: Design Parameters of Raw Mix RM-2

Raw Materials	LS-BI	MS-CH	RO - BI		LAT - BI		Coal ash absorption	
Proportion (%)	79.28	14.49	5.43		0.80		2.00	
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Raw Mix	34.63	12.81	3.31	3.19	41.01	3.11	0.40	0.40
Clinker	--	20.32	5.10	5.09	61.66	4.68	0.61	0.61
Modulii Values	LSF		SM		AM		Liquid content (%)	
Raw Mix	0.97		1.97		0.97		32.20	
Clinker	0.92		2.00		1.00			
Potential Phase Composition (%)	C_3S		C_2S		C_3A		C_4AF	
	55.11		16.72		4.86		15.44	

Table 8: Design Parameters of Raw Mix RM-3

Raw Materials	LS-BI	MS-CH	RO - BI	LAT - BI	Coal ash absorption			
Proportion (%)	76.21	18.59	4.43	0.76	2.00			
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Raw Mix	34.89	12.78	2.91	2.95	40.86	3.73	0.41	0.42
Clinker	--	20.34	4.52	4.74	61.68	5.63	0.61	0.62
Moduli Values	**LSF**	**SM**	**AM**	**Liquid content (%)**				
Raw Mix	0.98	2.18	1.01	30.91				
Clinker	0.93	2.20	1.05					
Potential Phase Composition (%)	C_3S	C_2S	C_3A	C_4AF				
	58.16	14.48	4.91	13.71				

Table 9: Design Parameters of Raw Mix RM-4

Raw Materials	LS-BI	MS-CH	RO - BI	LAT - BI	Coal ash absorption			
Proportion (%)	75.59	19.08	2.87	2.46	2.00			
Composition (%)	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Raw Mix	34.92	12.78	2.99	2.87	40.78	3.80	0.41	0.42
Clinker	--	20.36	4.64	4.63	61.59	5.74	0.61	0.62
Moduli Values	**LSF**	**SM**	**AM**	**Liquid content (%)**				
Raw Mix	0.98	2.18	0.96	30.94				
Clinker	0.93	2.20	1.00					
Potential Phase Composition (%)	C_3S	C_2S	C_3A	C_4AF				
	58.26	14.45	4.42	14.06				

5.2 Raw Mix Preparation

Raw mixes, RM-1 to RM-4 were prepared by taking weighed quantities of raw materials as per the designed composition as given in Tables 6-9. These mixes were ground and blended to fineness of 10 percent residue on 90μ (170 mesh). Raw meal nodules were prepared and dried in an electric oven at 105 $\pm$ 5°C for about 2 hrs before carrying out the to burnability studies.

5.3 Burnability Studies

Dried raw meal nodules prepared from raw mixes RM-1 to RM-4 were fired at the laboratory furnace at the temperature of 1300, 1350, 1400 and 1450°C for the retention time of 20 minutes and the clinker samples obtained were designated as CL-1, CL-2, CL-3 and CL-4 respectively. The results indicated the good burning characteristics of all the raw mixes and these four raw mixes are capable of yielding good quality clinker at the temperature of 1450°C with retention time of 20 minutes. The free lime content in all the clinker samples was found to be less than 0.50 percent at 1450°Cas given in Table 10. The X-ray diffraction studies of clinker samples indicated the development of good quality OPC clinker mineral phases, which were found to be in the range of designed compositions. The mineral phase investigation also indicated the presence of periclase (MgO) in small amount as shown in Fig 7-10.

Table 10: Burnability Studies of Cement Raw Mixes

(Retention Time 20 Minutes)

Sl. No.	Raw Mix	Temperature °C	Free Lime %
1	RM-1	1300	1.22
		1350	0.43
		1400	0.26
		1450	0.15
2	RM-2	1300	0.84
		1350	0.48
		1400	0.35
		1450	0.21
3	RM-3	1300	0.89
		1350	0.51
		1400	0.39
		1450	0.26
4	RM-4	1300	0.53
		1350	0.25
		1400	0.19
		1450	0.14

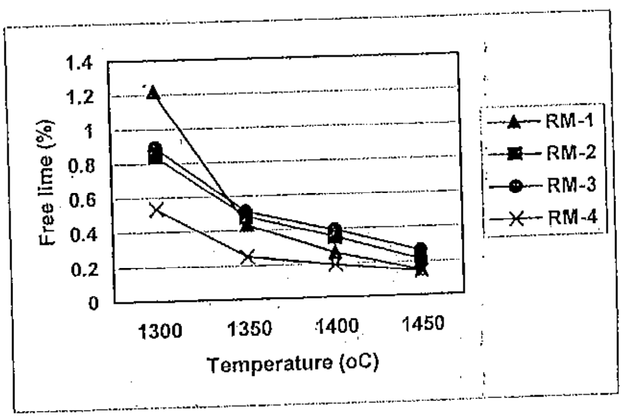

Fig. 6: Burnability Studies of Cement Raw Mixes

5.4 Optimization of Raw Mix

While designing the raw mixes every effort was made to keep the level of utilization of marble slurry (MS-CH) to the maximum possible extent but due to the presence of 15.86 percent MgO, the proportion of marble slurry in the

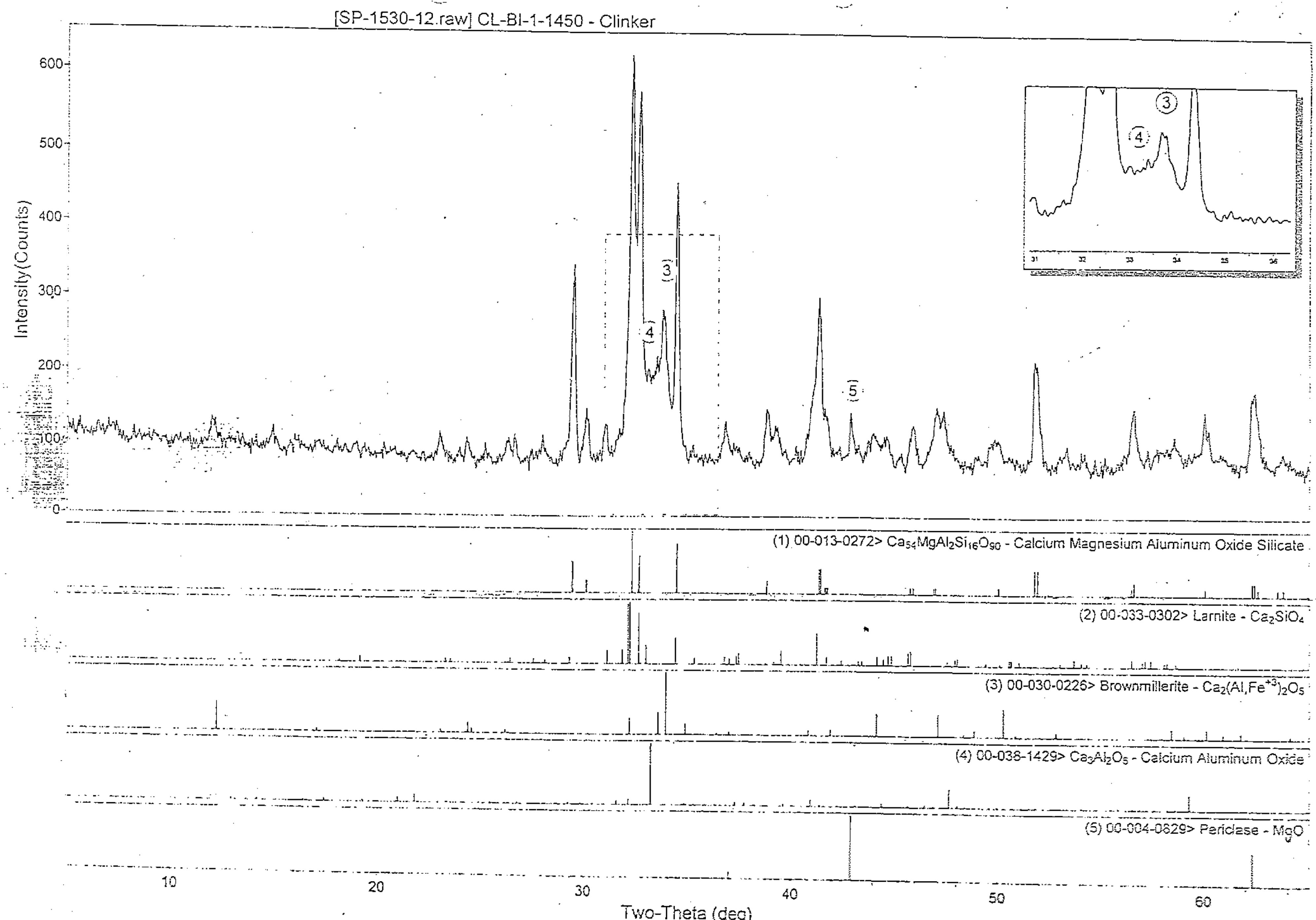

Fig.7: X-ray Diffractogram of clinker CL-BI-1-1450

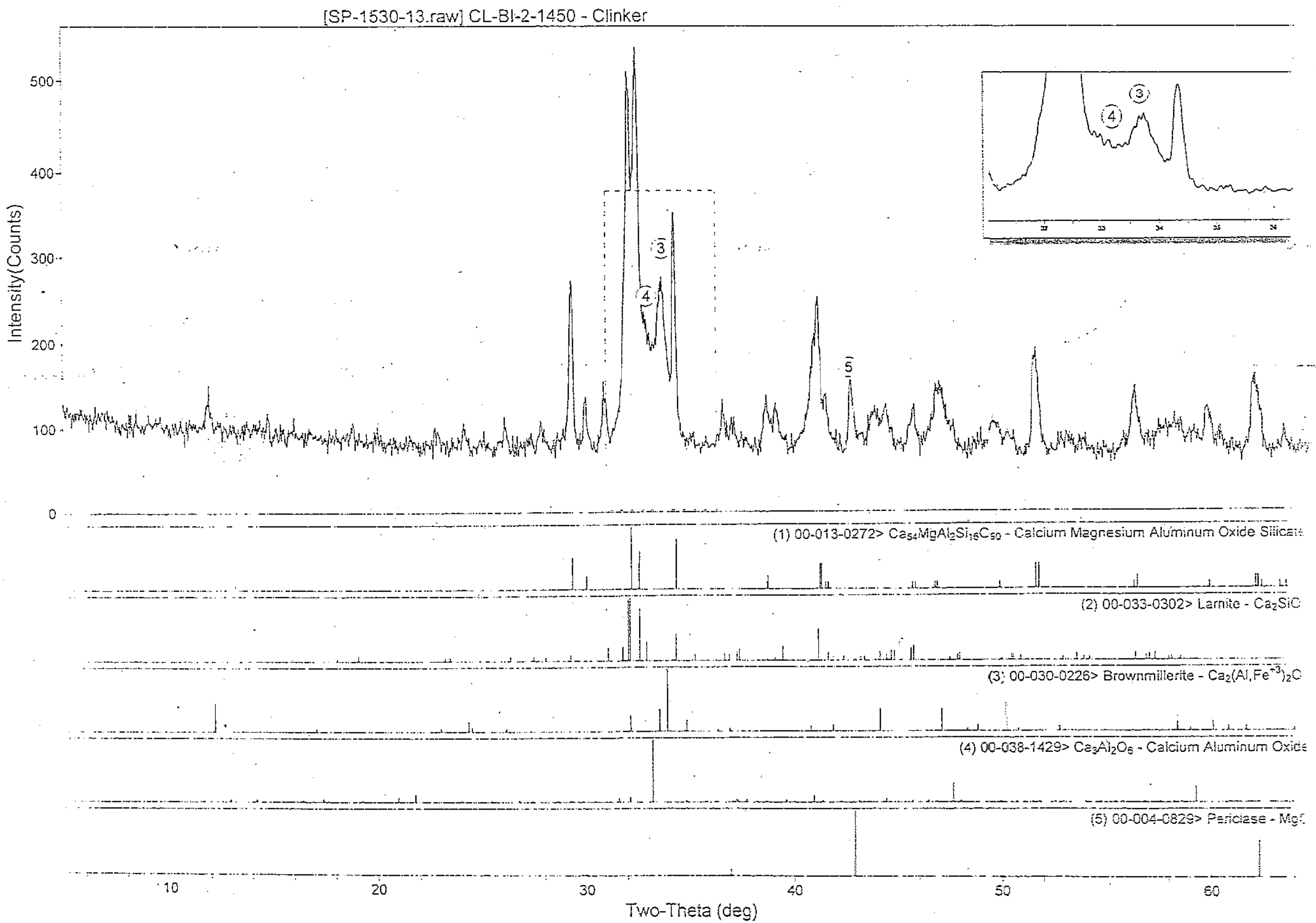

Fig.8: X-ray Diffractogram of clinker CL-BI-2-1450

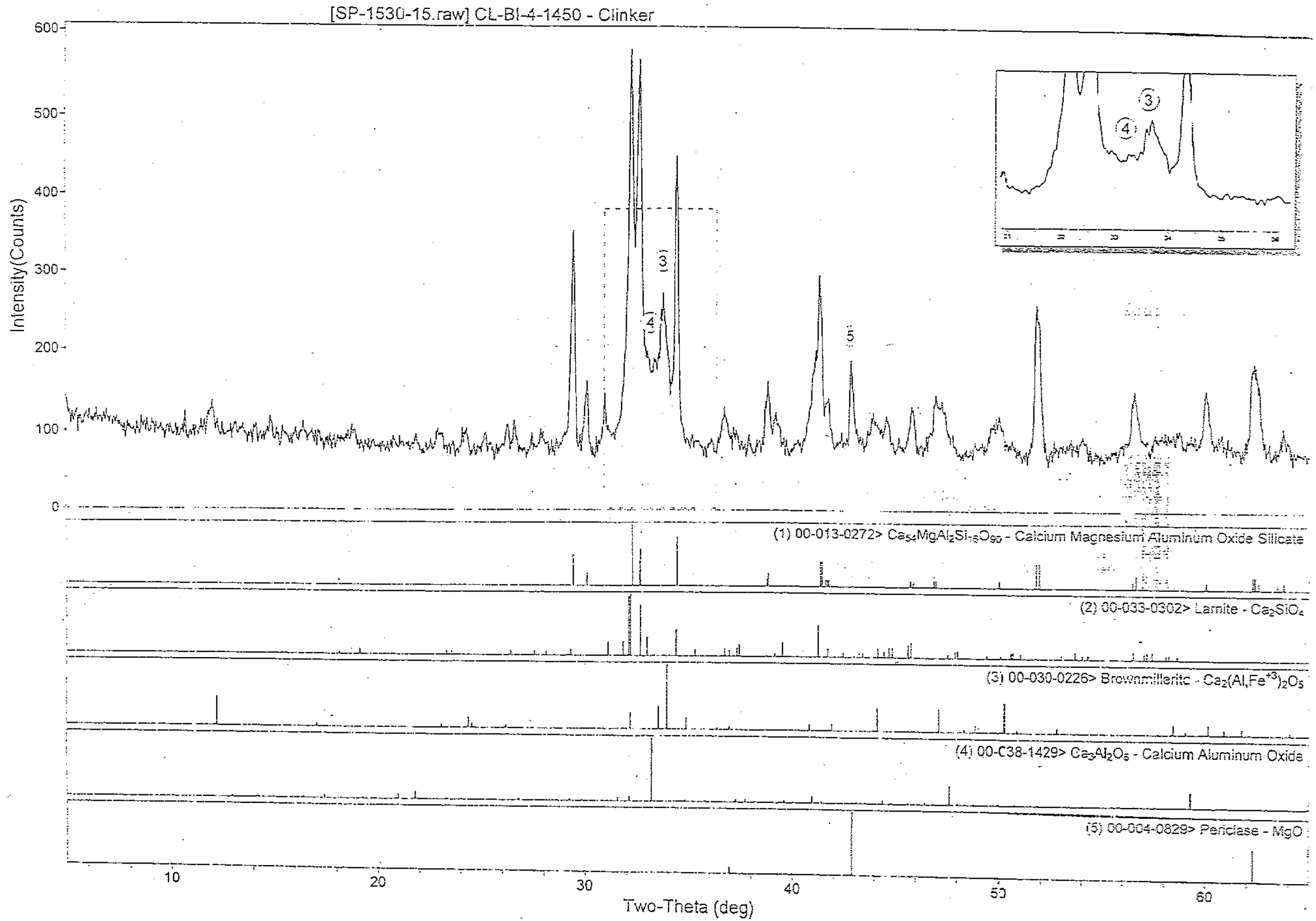

Fig. 10: X-ray Diffractogram of Clinker CL-BI-4-1450

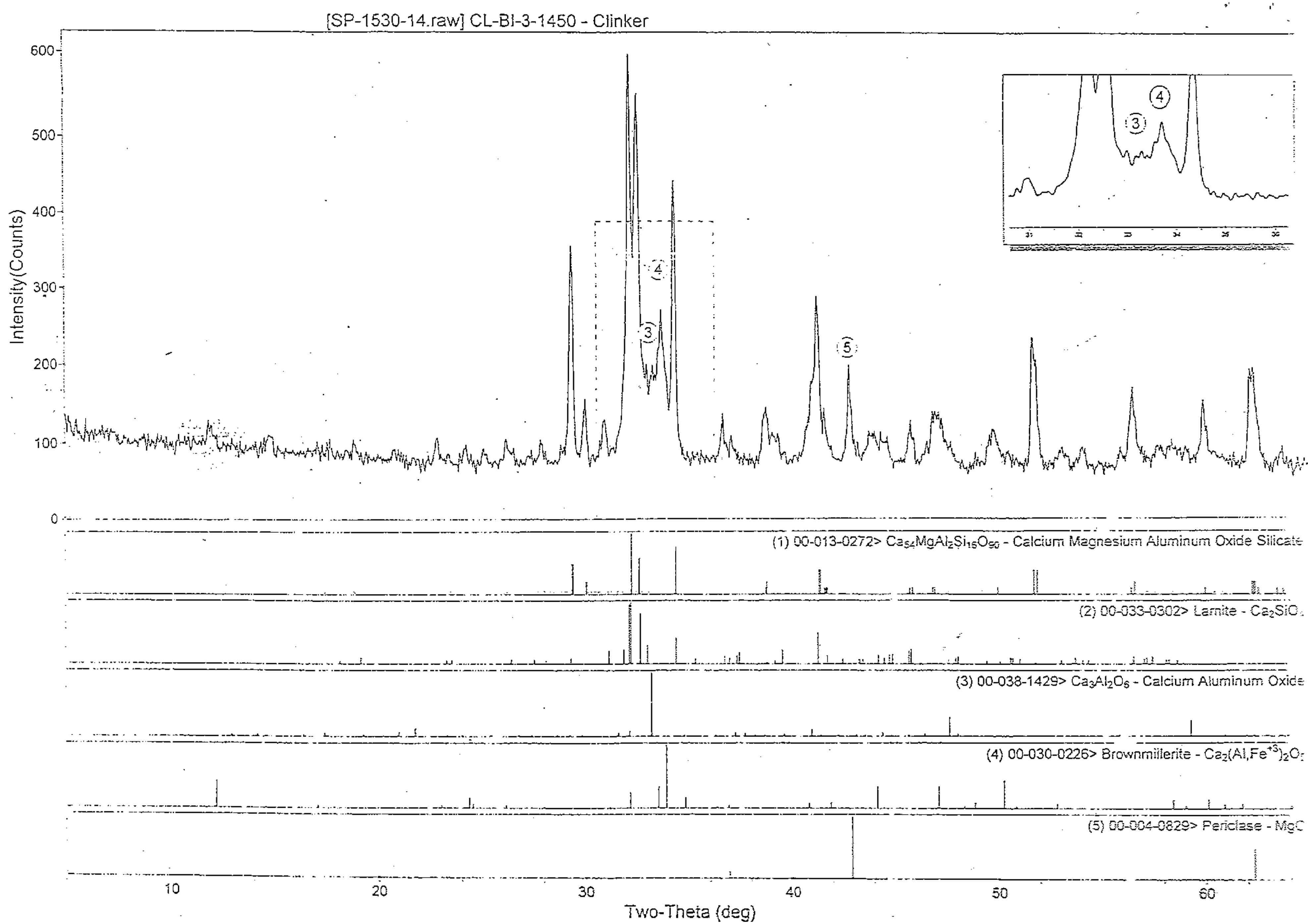

Fig.9: X-ray Diffractogram of clinker CL-BI-3-1450

designed raw mixes could not be increased beyond 19.08 percent in order to maintain MgO level in the clinker.

All the four designed raw mixes RM-1 to RM-4 yielded good quality OPC clinker at the temperature of 1450°C with a retention time of 20 minutes but keeping in view of maximum utilization of marble slurry with MgO content with in permissible limit, raw mix RM-1 was optimized for the preparation of bulk clinker.

Raw Mix, RM-1 was designed and prepared with three components viz. 81.52 percent limestone (LS-BI), 12.36 percent marble slurry (MS-CH), 5.74 percent red ochre (RO-BI) and 0.39 percent laterite (LT-BI). The ash absorption was kept at 2.00 percent.

6.0 PREPARATION AND EVALUATION OF BULK OPC CLINKER

6.1 Preparation of Bulk Clinker

Laboratory sample of raw mix, RM-1 was prepared for detailed investigations by taking weighed quantities of raw materials such as limestone, marble slurry, red ochre, laterite and coal ash, grind and blend them in a ball mill to a fineness of 10 percent residue on 90µ (170 mesh) sieve. The raw meal nodules were prepared in a pan nodulizer and dried in an electric oven at 105 ±5°C for 2 hours before firing in an electric furnace at the temperature of 1450°C for 20 minutes. The resultant clinker, designated as CL-1, was evaluated for chemical and mineralogical characteristics and the ordinary Portland cement (OPC-1) prepared thereof was evaluated for physical performance as per relevant Indian Standard Specification. The results are discussed below.

6.2 Evaluation of Bulk Clinker

Chemical Analysis

The chemical analysis of clinker, CL-1, was carried out as per Indian Standard Specification, IS: 4032-1985 and the results are given in Table 11. The free lime content in the clinker sample was found to be negligible. The SiO_2 and CaO contents in the clinker sample were found to be 20.34 and 62.05 percent respectively. The phase composition calculated by Bogue's formulae indicated that the quality of clinker is satisfactory and has potential of yielding good quality Ordinary Portland Cement. The SiO_2 and CaO contents in the clinker sample were found to be 20.34 and 62.05 percent respectively. The phase composition calculated by Bogue's formulae indicated that the quality of clinker is satisfactory and has potential of yielding good quality ordinary Portland cement.

Table 11: Chemical Analysis of Bulk Clinker CL-1

S. No.	Constituents Determined	Percent
1	LOI	0.21
2	SiO_2	20.34
3	Fe_2O_3	4.99
4	Al_2O_3	5.21
5	CaO	62.05
6	MgO	4.26
7	SO_3	Traces
8	Na_2O	0.65
9	K_2O	0.52
10	Cl^-	0.002
11	Insoluble Residue	0.34
12	CaO_f	0.20

Mineralogical Analysis

The optimized OPC clinker, CL-1, was evaluated for mineralogical composition using optical microscopy and indicated the presence of 52 and 30 percent alite and belite phases respectively with average grain size of 35 and 33 micron. The optical micrograph of clinker sample indicated the homogenous distribution of well-developed phases. The optical micrograph of clinker was shown in Plate1. Periclase content was found to be 4 percent only.

Table 12 : Mineral Phase Analysis of Clinker Sample (CL-1) by Optical Microscopy

Sl. No.	Clinker Sample	Phases	Quantity (%)	Granulometry (µm)		
				Min.	Max.	Avg. Size
1.	CL-1	C_3S	52	3	46	35
		C_2S	37	2	42	33
		C_3A } C_4AF & interstistitial	11	-	-	-
		CaO_f	---			

Plate 4: Optical Micrograph of Clinker Sample CL-1

The chemical-mineralogical investigation of the clinker (CL-1) sample indicated good quality of OPC clinker and found suitable for the manufacture of ordinary Portland cement.

7.0 PREPARATION OF ORDINARY PORTLAND CEMENT (OPC) AND ITS EVALUATION

7.1 Preparation of ordinary Portland cement

Ordinary Portland cement, OPC-1, was prepared by crushing and grinding of the bulk clinker (CL-1) with 5.5 percent gypsum to a fineness level of ~300 m^2/kg and tested for setting time, compressive strength, Le-chatelier and autoclave expansion tests as per the relevant Indian Standard Specification IS: 4031-1988 and the results are discussed below.

7.2 Evaluation of ordinary Portland cement

Setting Time

The initial and final setting time of ordinary Portland cement prepared in laboratory from bulk clinker, CL-1, were determined as per IS: 4031-1989 and found to be 84 and 152 minutes respectively. The OPC-1 conformed to the requirements of IS: 8112-1989 with respect to setting time. The results are given in Table 12.

Compressive Strength

The compressive strength of ordinary Portland cement (OPC-1) was determined as per IS: 4031-1988 and the results are given in Table 12. Compressive strength at 3, 7 and 28 days were found to be 25.2, 37.5 and 60.8 MPa. The OPC-1 thus conforms to all requirements of relevant Indian Standard Specification IS: 8112-1989 for OPC-43 grade. The values of compressive strength of above cement also meet out the requirement of IS: 12269-1987 for OPC-53 grade cement.

Soundness

Autoclave and Le-chatelier expansion tests on OPC-1 cement were carried out as per the procedures laid down in IS: 4031-1989. Autoclave expansion was found to be 0.021 percent and Le-chatelier expansion to be 1.0 mm. Results indicated high volume stability of the cement sample.

The results of physical characteristics of ordinary Portland cement thus prepared indicated that the cement sample conforms all the requirements of OPC-43 grade and even those of OPC-53 grade cement. Therefore, it is established that marble slurry sample up to the extent of 12.36 percent can be gainfully utilized in the manufacture of ordinary Portland cement along with other conventional raw materials limestone, red ochre and laterite without affecting its chemical, mineralogical and physical characteristics.

Table 12: Performance of Ordinary Portland Cement (OPC-1)

Sl. No.	Property	OPC- 1	Requirement of IS: 12269-1987 (53 Grade OPC)
1	Fineness (M^2/kg)	301.1	Not less than 225
2	Setting Times (Min.)		
	Initial	84	Not less than 30
	Final	152	Not less than 600
3	Compressive Strength (N/mm^2)		
	3 Days	25.2	Not less than 27
	7 Days	37.5	Not less than 37
	28 Days	60.8	Not less than 53
4	Soundness		
	Le-chatelier (mm)	1.0	Not more than 10
	Autoclave (%)	0.021	Not more than 0.8

8.0 UTILIZATION OF MARBLE SLURRY AS MINERAL ADMIXTURE IN CEMENT

The addition of materials such as limestone, slag, fly ash silica fume, rice husk ash and metakaolinite etc at various stages of cement manufacturing has been a common practice particularly in view of cost saving and environmental protecting factors associated with these materials. The Bureau of Indian Standards has also allowed mineral addition in cement in the form of amendment vide DOC: CED 2 (5894) December 1999 as draft amendment No.7 December 2003 to IS: 8112:1989. BIS permits addition of these materials during clinker grinding. The above amendment also indicated that the limestone sample to be used as performance improver in cement shall contain more than 75 percent $CaCO_3$ content ie CaO content should not be less than 42 percent. The CaO content in marble slurry sample from Chittorgarh marble slurry cluster was found to be 30.88 percent only. The investigations were taken up with the marble slurry sample procured and 3 and 5 percent dose was taken for preparation of cement samples.

9.0 PREPARATION OF CEMENT SAMPLES

Marble slurry (MS-CH) added cement samples were prepared using clinker (CL-BI) and gypsum (GYP-BI) samples by intergrinding of clinker and gypsum with 3 and 5 percent dosage of marble slurry (MS-CH). Various cement samples were prepared in the laboratory ball mill of the capacity of 10 kg. Apart from these, a control ordinary Portland cement (OPC-BI-C) was also prepared for parallel study. In all the cases, the level of gypsum was kept at 5 percent. These samples were study for their physical performance and results are given below.

9.1 PHYSICAL PERFORMANCE

The effect intergrinding of 3 and 5 percent of marble slurry with clinker and gypsum on the physical properties of the resultant cement samples, OPC-BI-3 and OPC-BI-5 along with control sample, OPC-BI-C, is given in Table 13. The results of the investigations are given below.

Fineness

The blaine's fineness of cement samples with marble slurry addition and control OPC was kept at almost same fineness level of 315, 311 and 318 m^2/kg for the comparative study as given in Table 13.

Setting Time

It was observed that on addition of marble slurry (MS-CH), the initial and final setting time of the resultant cement was found to be slightly increased. The values of initial setting time of OPC-BI-C, OPC-BI-3 and OPC-BI-5 were found to be 135, 140 and 146 minutes & their final setting times were 205, 210 and 215 minutes respectively.

Compressive Strength

The determination of compressive strength of control cement (OPC-C) and cement samples with marble slurry addition OPC-BI-3 and OPC-BI-5 indicated that marble slurry addition has resulted in enhancement of the compressive strength at all ages as given in Table 13.

Soundness

The values of Le-chatlier expansion of control cement was found to be 1 mm. Addition of marble slurry resulted in marginally decrease in the expansion of the resulted cement.

The above performance evaluation of the cement samples with marble slurry from chittorgarh cluster established that marble slurry improved the performance (in terms of compressive strength) of the cement.

TABLE 13: PERFORMANCE OF CEMENT PREPARED FROM CLINKER AND MARBLE SLURRY (MS-CH)

Sl. No.	Property	OPC-C	OPC-BI-3	OPC-BI-5	Requirement of IS: 8112-1989 (Amendment No. 7) (43 Grade OPC)
1	Fineness (M^2/kg)	315	311	318	Not less than 225
2	Setting Times (Min.)				
	Initial	135	140	146	Not less than 30
	Final	205	210	215	Not less than 600
3	Comp. Strength (N/mm^2)				
	3 Days	27.3	27.5	27.9	Not less than 27
	7 Days	38.0	39.2	40.3	Not less than 37
	28 Days	53.0	53.7	54.3	Not less than 53
4	Soundness				
	Le-chatelier (mm)	1.0	1.0	1.0	Not more than 10
	Autoclave (%)	0.026	0.024	0.020	Not more than 0.8

10. Techno-Economics

The economics of utilization of marble slurry in the manufacture of cement will depend upon the following factors:

1. Distance of cement plant from the nearest marble slurry disposal site.
2. Physical state in which the marble slurry is available for use.
3. The utilization level of marble slurry for the manufacture of cement

To arrive at the techno-economic benefits of using marble slurry as a raw mix component for the manufacture of OPC clinker and as a mineral addition (partial replacement of OPC clinker) for the manufacture of cement samples, the following assumptions were made:

Assumptions:

1. Cement plant is not located very far away in order to minimize transportation charges
2. Sun dried marble slurry is available on site.
3. Marble slurry is available free of cost.
4. Cost of production of clinker at the plant worked out to be approximately Rs 1000/MT.
5. Cost towards other parameters such as grinding energy, additives, packing etc. remains comparable.

Marble slurry as raw mix component for manufacture of OPC clinker:

A. In general, ~ 1.5 MT of raw meal needed for 1.0 MT clinker. When ~ 95 percent limestone is used in raw meal, the cost of 1.425 MT limestone = Rs 213.75 (considering landing cost of limestone Rs 150/MT).

B. When 5 percent limestone is replaced with marble slurry as a general case, then

Cost of 1.35 MT of limestone = Rs 202.50
Cost of 0.075 MT of marble slurry = Rs 7.50
Total cost = Rs 210 per MT
(Considering landing cost of dry marble slurry Rs 100/MT)

C. Net saving in cost of production of 1 MT of clinker when marble slurry used as raw mix component (A-B): Rs 3.75.

D. **Net saving in production cost for 1 million tonne OPC clinker: Rs 3.75 million**

Marble slurry as mineral admixture for manufacture of cement:

A. Cost of 1 MT of clinker = Rs 1,000/-

B. With 95 percent clinker in manufacture of 1 MT OPC, the effective cost of clinker = Rs 950/-

C. When 5 percent clinker is replaced with marble slurry, then the effective cost = Rs 905

D. Net saving in manufacture of 1 MT of cement with addition of marble slurry = Rs 45 per MT

E. Net saving in production for one million tonne of cement: Rs 45 million

Annexure - II

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A new technology of marble slurry waste utilisation in roads

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Marble slurry dust (MSD, a waste of marble industry, finds bulk utilization potential in roads. This study indicates that besides embankment construction with this waste, 20-30% of soil can be replaced by MSD for sub-grade preparation. Technology has been validated by taking full scale trials in the field.

Keywords: Embankment, Marble slurry dust (MSD), Roads

Introduction

Around 4000 marble mines and 1100 marble processing units, spread over 16 districts of Rajasthan[1], generate huge quantity of marble dust (5-6 million tonnes/y) in the form of slurry during processing and slabing of marble stones. Indiscriminate disposal of marble slurry dust (MSD), mostly on road sides, is causing problems of drainage, flow regime, air pollution and damage of agriculture land. Extensive research work has been carried out at CRRI, New Delhi, for bulk utilization of this waste in road pavement layers, embankments and in concrete works[2-4].

This study presents work carried out at CRRI on pavement design, methodology adopted for construction, performance evaluation, economy achieved etc. for utilization of MSD in roads.

Experimental

Materials and Laboratory Studies

From Rajsamand District, Rajasthan (India), soil sample was collected from construction site at Sirola to Kuncholi Road and MSD from site at Moonlight Marbles. MSD and soil samples were prepared for various tests for their characterization. Soil-MSD mixes were also prepared using various proportions of MSD. Dry soil samples were prepared as per IS: 2720, Part 1[5].

Grain size analysis[6] of soil specimen was carried out for different sieve size as follows: 40 mm, 100%; 20 mm, 95.5%; 10 mm, 93.3%; 4.75 mm, 90.90%; 2.36 mm, 85.9%; 1.18 mm, 78.8%; 600 µm, 70.8%; 425 µm, 66.0%; 300 µm, 54.3%; 150 µm, 37.3%; and 75 µm, 27.6%. Grain size analysis of MSD gave complete passing through 75µm sieve.

Liquid limit test[7] and plastic limit test[7] were performed on soils, MSD and on soil-MSD mixes (Table 1). Based of grain-size analysis and plasticity index, soil and MSD were classified as per unified soil classification system. Proctor test[8], California Bearing ratio (CBR) test[9] and unconfined compressive strength (UCS) test[10] were performed on soils, MSD and soil-MSD mixes. As CBR values corresponding to a penetration of 5 mm exceeded that for 2.5 mm, test was repeated and reported results of bearing ratio correspond to 5 mm penetration (Table 1). Direct shear test[11] on soil, MSD and soil-20% MSD mixes was done to determine cohesion (c) and angle of internal friction (f), respectively, values are as follows: soil, 0.03 kg/cm^2, 40°; MSD, 0.2 kg/cm^2, 32°; and soil-20% MSD, 0.13 kg/cm^2, 38°.

Design of Road Pavement

A pavement is designed to support wheel loads. Topmost layer is surfacing, to provide a smooth, tough, dust free, reasonably water proof and strong layer. Base, which comes immediately next below, is medium, through which stresses imposed are distributed evenly. Additional help in distributing loads is provided by sub-base layer. Sub-grade is compacted natural earth immediately below pavement layers. Top of sub-grade is also known as formation level.

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Table 1—Engineering properties of soil, MSD and soil - MSD mixes

Engineering properties	Soil	Soil+ 10% MSD	Soil+ 20%MSD	Soil + 25%MSD	Soil + 30%MSD	MSD
Liquid limit ,%	29	28.4	27. 5	26.5	25.6	25
Plastic limit ,%	22.5	21.8	20.8	19.7	18.6	17.8
Plasticity Index, %	6.5	6.6	6.7	6.8	7.0	7.2
Maximum dry density, g/cc	1.9	1.95	1.93	1.92	1.914	1.82
Optimum moisturecontent, %	11.0	11.6	11.9	12.1	12.1	12.5
CBR ratio, %	12.5	16.5	17.7	15.4	10.2	4.0
Saturated moisture content for CBR test	13.3	11.5	11.2	11.1	15.6	18.7
Unconfined compressive strength, kg/cm²	1.3	1.4	1.4	1.5	1.75	-

An adequately constructed embankment is provided for successful performance of a road pavement. Generally, soils having high shearing & bearing strength, density (Min., 1.65 g/cc) and that do not exhibit large volume change are preferred. Design of road pavement depends on CBR value of sub-grade. CBR of *in-situ* soil was 12.5% and that of soil – MSD mix was 17.7%. Laboratory studies suggest that MSD (20%) mixed with soil (on dry weight basis) gives optimum results (Fig. 1).

For low volume traffic, design life and design CBR of sub-grade soil etc, pavement thickness have been worked out[12]. Low cohesion (c = 0.20), high angle of internal friction (ϕ =32) and density (1.82 g/cc) of MSD have potential in embankment preparation. Since site provided for construction of demonstration road stretch had no low line area, an embankment in cutting/ confined condition (1m x 4m x 150m) was constructed with 100% MSD to study settlement behaviour of MSD under prevailing load and environment conditions.

Data used for pavement design of single lane carriage way is as follows: initial traffic (A), 50 CVD; vehicle damage factor (F), 1.5; traffic growth rate (r), 7.5%; design life (n), 10 y; CBR of soil, 12.5%; CBR of soil + 20% MSD mix, 17.7%; design CBR for soil & soil-MSD mix 8.3 & 11.8% (assumed 2/3 of laboratory CBR). As per design calculations, lane distribution factor (D) is 1. Cumulative number (N) of standard axles to be catered for in design life is calculated as

$$N = 365\ (1+r)^{n} - 1 / r \times ADF$$
$$= 365\ (1+.075)^{10} - 1 / .075 \times 50 \times 1 \times 1.5$$
$$= 0.3873 \text{ msa}$$

As per IRC 37 – 2001, for 7-10 CBR and 1 msa traffic, thickness of pavement correspond to 375 mm. Therefore, base thickness will be 225 mm and GSB 150 mm.

Construction of Test and Control Sections

As a first step of construction, clearing of shrubs, stumps, roots, undergrowth, rubbish and other objectionable material from already marked area was done.

Mixing of MSD and Soil

Measured amounts of MSD and soil (1:5) to be mixed were piled up in open field. Soil and MSD were mixed using JCB till a homogenous mix was obtained. It was ensured that mix gives the same maximum dry density (MDD) as determined in laboratory.

Construction of Sub-grade and Embankment

Local soil or soil-MSD mix used for construction of conventional and test sections respectively was spread over prepared surface. For proper compaction, sub-grade was compacted in uniform layers (25 cm loose thickness) and at optimum moisture content (OMC). Next layer was allowed only after attaining required compaction of first layer. During construction, thickness of loose and compacted layers were checked. To check *in-situ* density (97%), sand replacement method was adopted[13]. In case moisture was above OMC, layer was allowed to dry in sunlight and in case it was below OMC, water was added to attain OMC level[14]. In embankment (1m x 4m x 150m), 100% MSD was compacted at OMC in layers till it attained 95% MDD. Compaction and quality check was similar as done in sub-grade preparation.

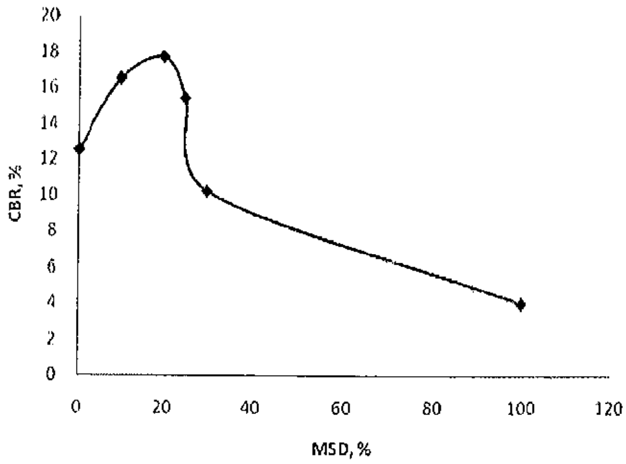

Fig. 1—Effect of MSD on CBR of soil

Construction of Granular sub-base (GSB), Water Bound Macadam (WBM) and Premix Carpet (PMC)

GSB (150 mm), WBM and PMC were laid over prepared sub grade as per standard procedures[15]. Base-course (WBM) was constructed in three layers (75 mm each). A first and second layer was of G-II and third was of G-III as per Table No. 400-7. Screening and binding materials were also as per Table No. 400-8 & 400-9 respectively. Spreading and consolidation of sub base and premix surfacing (20 mm) with seal coat laid over base-course (WBM) were in accordance with MORSTH guidelines.

Results

Pavement Performance Evaluation

Pavement Distress Measurement

Common types of distresses encountered on pavements and considered for measurement are cracking (alligator cracking, map/block cracking, longitudinal and transverse cracking, edge cracking etc.), potholes, raveling, shoving, bleeding, depression/settlement, edge breaking, patch work. For measurements and recording data on different forms of distress, sections were divided into subsections (5 m each), with clearly marking start and end points. Subsections were further divided into three equal longitudinal left, center and right strips. Different distresses were marked, carefully measured separately in regular shapes and recorded subsection and strip wise on standard proforma. In case of single longitudinal and transverse cracks, affected area is taken as the product of actual length of crack and 0.3 m width strip. Cracking is further defined with 3 severity levels (narrow, medium and wide).

Riding Quality Measurements

Riding quality, road user comfort and vehicle operation costs are directly influenced by roughness of pavement surface. Roughness was measured with DIPSTICK (auto read road profiler). Left and right wheel paths were identified at a distance of 0.9 m from each edge and dipstick measurements were taken on both wheel paths to get roughness in terms of IRI (international roughness index) and same was converted into BI (bump integrator) terms using World Bank equation[16], BI = 630 (IRI) $^{1.12}$.

Deflection Measurements

Structural conditions of test sections were evaluated by response in terms of deflection under a standard rear axle load (8170 kg) of a loaded truck (tyre pressure, 5.6 kg/cm^2). Deflection measurements[17] were taken on 6 points in a 45 m long section, in a staggered manner. These points were located at 0.9 m from respective edges on sections of single carriage-way. All necessary corrections for temperature and moisture were applied to get corrected characteristic rebound deflection.

Sub-grade Moisture

Moisture content in sub-grade level varies significantly throughout the year due to soil type and its level of compaction, pavement materials and their compaction level, surface condition, rainfall temperatures, depth of water table and height of embankment, surface and subsurface drainage etc. To find out moisture content, a pit of suitable size was dug on shoulder adjoining pavement section in transition length portion, up to sub-grade level. Two samples of soil at 50 mm below sub-grade top were taken out and immediately sealed in labeled sample tins/plastic containers to avoid evaporation. Subsequently, moisture content was determined as per IS: 2720 (part-II) and recorded. These values were used for applying seasonal corrections to rebound deflection data.

Data Analysis on Distress, Roughness and Deflection Progression

Data was collected from all five sections (150 m each, starting from Sirola cross section) as follows: 1st section , control section ; 2nd section , test section having 20% MSD in sub-grade -01; 3rd section, test section having 20% MSD in sub-grade and over embankment constructed of 100% MSD-02; 4th section, test section having 20% MSD in sub-grade-03; 5th section , control

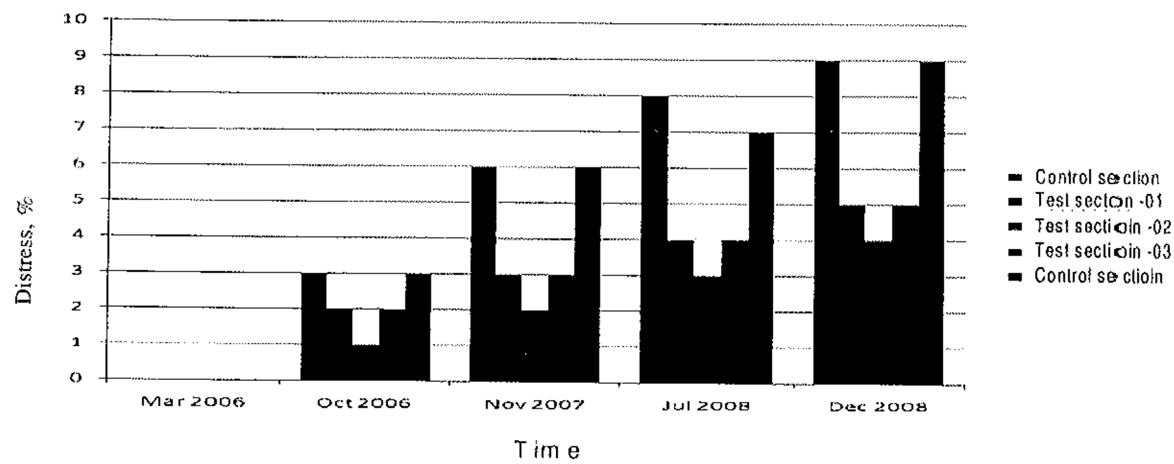

Fig. 2—Distress values on test sections at Kucholi village road

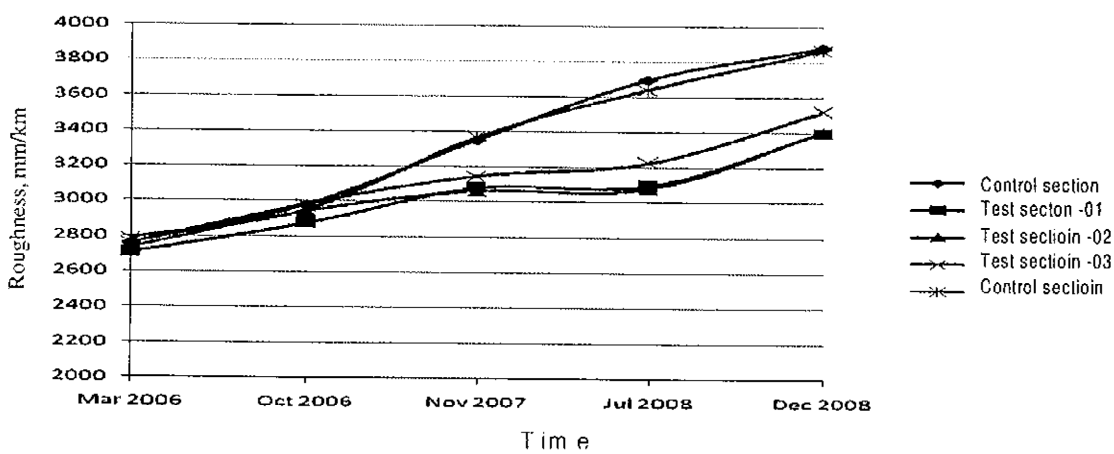

Fig. 3—Roughness progression values on Kucholi village link road

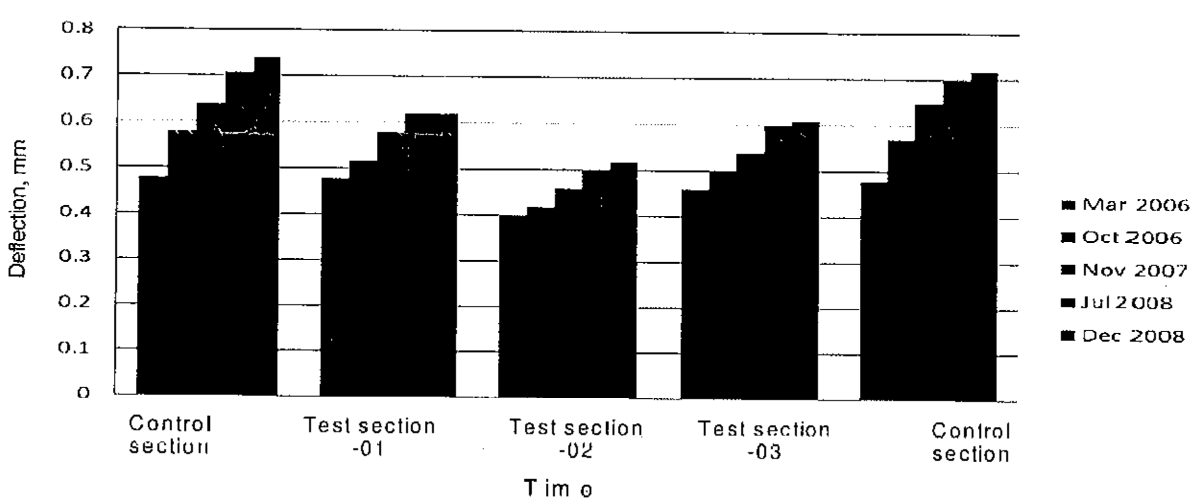

Fig. 4—Progression of deflection values on Kucholi village link road

section. Over study period, distress progression was found as follows: test sections, 3-5%; and control sections, 7-9% (Fig. 2).

Roughness progression in test sections (1-3) is less (687-757 mm/km) as compared to control sections (1074-1120 mm/km). In case of test section no. 02, which is constructed over MSD embankment, roughness is minimum (Fig. 3). Structural strength decreased in control (0.22 mm, 54%) and test sections (0.12 mm, 30%), indicating a residual life of 46% and 70% in control and test sections respectively (Fig. 4). This suggests that control sections will require renewal in 1-2 years while tests sections can be under service without any treatment for another 4-5 years.

Cost Benefit Analysis for Single Lane Pavemant (3.75 m carriageway, 1.0 km long)

Soil requirement for sub-grade preparation (600 mm height) = 5000 m^3
MSD requirement (20% by wt of soil)
= 1000 m^3/ 1900 tonne

Saving in sub-grade soil using MSD
= 1000 m^3
Cost of this soil
= 1.0 Lakh

Extra cost for mixing of MSD & soil + lead & lift (10 km), mixing with JCB
JCB charges/ day [mixing capacity (300 - 400 m^3/d) @ Rs. 2/- / m^3] = Rs 600/-
Mixing cost = Rs 10,000/-; transportation (lead & lift) = Rs 15,000/-
Total = Rs 25,000/-
Net saving = Rs 75,000/-

Discussion

Grain size analysis revealed that soil collected from site is coarse grained. Plasticity tests revealed that soil is sand associated with silt of low compressibility (SM). MSD is very fine and passes completely through 75 µm sieve. Dust sample used in construction work belong to CL-ML group (mixture of clay and silt of low compressibility). Effect of mixing MSD (up to 40%) with soil resulted in minor changes in plasticity of soil .Change in plastic behavior of soil is related to plasticity of added dust. Load bearing capacity (CBR test) of soil improved with addition of MSD (up to 20%). Dust made soil slightly cohesive and resulted in better compaction of pavement layers. UCS of soils with MSD also improved. MSD has low cohesion and high coefficient of internal friction.

Construction site provided for demonstration road stretch was passing through agriculture land having irrigation drains on both sides. Normal rainfall of the area is 550 mm. During 2006, 2007 & 2008, rainfall recorded was 774, 591 and 345 mm. Despite, high rainfall and submerged conditions, test sections showed no signs of distress over study period. Under performance evaluation, test sections constructed using MSD were found having more strength and stability as compared to the control sections.Distress progression is slow in case of test sections as compared to conventional sections. From cost benefit analysis, use of MSD in sub-grade preparation for a double lane road would save Rs 1,50,00/-per km. In multi lane roads and for high embankments, savings would increase many folds.

Conclusions

MSD can be gainfully utilised in bulk quantities in construction of road pavement layers and in embankments. Use of MSD results in saving of soil and savings on difference in cost of natural material soil, besides protection of environment.

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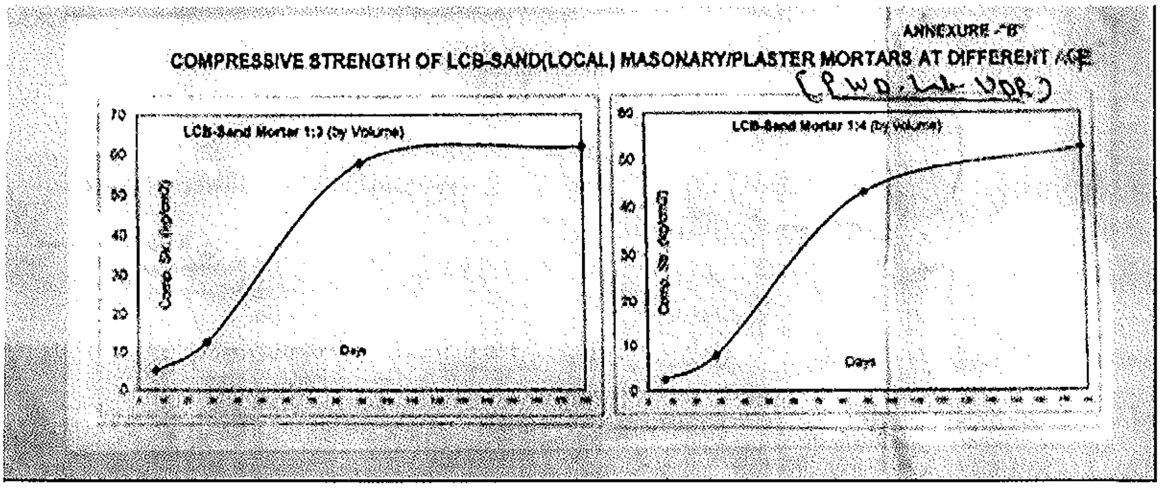
Annexure-III

Binder made from Marble Slurry: a solution to the problem

(Shri Sampat Lal Surana, Mechanical Engineer, Jaipur)

Comparison of Physical Properties of Low cost Shree Binder with (Masonry Cement) As per IS: 3466-1988

S.No.	Characteristics	Requirement as per 3466-1988	Results of Govt. approved Lab – low cost shree binder	Required as per PWD Table	Remarks
1	Fineness residue on 45-micron IS Sieve, Max, percent(by wet sieving)	15	4.00		Better plastic finish
2	Setting Time (by Vicat Apartments) • Initial ,Min • Final, Max	90 min 24hrs	4 to 8hrs 18 to 22hrs		Long Working Period Easy to use
3	Soundness • Le-chatelier expansion, Max • Autoclave expansion	10mm 1 percent	4.85mm 0.082 percent		Lesser cracks in coal
4	Compressive strength: Average compressive strength of not less than 3 mortar cubes of 50mm size, composed of one part masonry cement / low cost shree binder and 3 parts standard sand by volume, Min 7 days 28 days	25 kg/cm^2 50 kg/cm^2	15 to 22 kg/cm^2 30 to 66kg /cm^2	15 kg /cm^2 30 to 50 kg/cm^2	Fulfill the requirements as per the state PWD norms
5	Water Retention: Flow after suction of mortar composed of 1 part masonry cement / low cost shree binder and 3 parts standard sand by volume, Min	60 percent of original flow	30 percent of original flow		Lesser curing required



Comparison-Energy Consumption / Conservation/ Effiency

Energy	Low cost binder	Lime	Cement
Coal	Not required	100 Kgs per ton (10%) costing Rs 450/- per ton	750 calories for per ton of cement production (i.e. 8 to 13% of cost)
Electricity	15 units per hour for 750 Kgs per hour low cost binder productivity i.e. 20 units per ton production of I.C.B. costing Rs. 84/- per ton	Not required	75 units per ton manufacturing of cement @ Rs. 4.20 per unit i.e. Rs 315/- pe metric ton
Petroleum	Not required	Not required	Not required