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# PRE-FABRICATED GYPSUM BOARDS

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## SUMMARY

Gypsum, a cheap industrial mineral, when calcined at relatively low temperatures results into a cementitious material of considerable value, the use of which may bring economy in cement and brick consumption and also in overall cost of the structures, particularly the multi-storyed ones. It has a long and important history as a building component in the form of partitions, even load bearing walls; fibrous plaster sheetings for internal cladding; false ceilings; precast building blocks etc. Pakistan abounds in easily mineable high quality gypsum which is not being put to any significant use in the construction industry. The Building Research Station Lahore, has endeavoured to study this material to reawaken an interest in the cast gypsum construction so as to popularise its use as an important building material.

The paper gives historical appraisal of prefabricatory methods in gypsum and discusses the quality of indigenous rock deposits and the manufactured plasters alongwith the manufacturing technique of precast soild/hollow blocks; thin sheetings and the light weight aerated/bloated blocks. Partition walls constructed with solid blocks as well as fibrous sheetings have also been described. The brittleness of gypsum in thin sections has been overcome by incorporating cheap reinforcement.

## INTRODUCTION

Prefabrication refers to any integrated system of construction in which the parts have been prepared under factory conditions[1] away from site and the preassembly of such parts into complete units of a building. It is a continuing trend with many fluctuations and aims at turning a scattered, handicraft industry into a centralized one by mass production of panel houses for a national market. Its wide application is one of the most important conditions for increasing the rate of construction

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and decreasing costs. Prefabrication method, when employed, can shorten[2] construction period by 30 percent, save labour by 20%, save formwork by 60%, as compared to cast-in-situ method. The consumption of ingredient materials is nearly the same, yet the quality is better ensured.

Prefabricated gypsum has a long and important history as a construction material and is today develping further in the general concept of industrialized building. Gypsum[3] was used by most of the earlier Asian Civilizations; through the Middle Ages in Europe; over 4 thousand[4] years ago in Egypt and many mediterranian Middle East Countries and in the 16th Century and perhaps earlier in those parts of England and France where it was plentiful.

In about 1887, cast[5] gypsum with a filler was extensively used in Germany for walls and ceilings. By 1919, precast gypsum units reinforced with steel mesh were being used in the United States for roofing decks and floors. Large scale use of gypsum boards in the United States and Japan was encouraged by the Building Laws[6] stipulating the use of fire resistant and adiabatic materials. Gypsum resources in Japan are very scarce. But a large quantity of chemical gypsum is produced as a bye-product of phosphoric acid industry and is put to use in the building industry in addition to its import. The production[7] of gypsum plaster had increased from 8900 tonnes in 1957 to 1.2 million tonnes in 1966 while that of gypsum boards from 14 million $m^2$ in 1957 to 124 million $m^2$ in 1966. Metal strip reinforced gypsum slabs have been used since long for house building in the U.S.S.R.

Gypsum plaster board, a substitute for lath and plaster ceiling, has been increasingly used in speculatively built houses in England[1]. During the War and the ensuing shortages of various materials, gypsum was used for much war damage repair work and as a substitute for other kinds of wall lining in houses that were developed in the post war years. Fibrous plaster, a form of pre-fabricated plaster already extensively used before the turn of the century(1885), was revived in a more utiliterion form in early fifties. Cast plaster panels separated by a honey-comb core of plaster reinforced with jute fabric developed in 1947-1950 have emerged as the now well-known Bellrock[1,6] plaster panels used all over England for partitions and wall linings in 3,4 & 6 inch(76.2; 101.6 and 152.4 mm) thickness, and on which no further plastering is required. These panels are also used for load bearing purposes and as inner leaves of cavity walls in houses. External walls built with 6-inch(152.4 mm) panels of this type, suitably water-proofed have also proved satisfactory. A type of plaster board partition unit(overall thickness 2¼ to 2½ inch or 57.15 to 63.5 mm) composed of two layers of 3/4"(9.53 mm) and ½" (12.7 mm) plaster board bonded by a 'honeycomb' core of coated cardboard has also been developed and marketed since 1950 under Trade[1,8] name "Paramount".

Available in various storey-height units of 2 to 4 feet (61 to 122 cm) width, it has now become well established as a normal method of partitioning. Prefabricatory methods in gypsum in Australia and Newzealand stemmed from government action as well as from the initiative of certain enterpreneurs. During the present century, sheetings and boards cast infactory(more than 500 factories in Australia [7,8,9] alone) have become appreciably prominent and have mostly replaced the plaster applied directly to the wall surfaces in about 70% of domestic buildings[10]. The boards(generally of room height, 60-120 Cm width and 25-100 mm thickness) consist of calendered panels covered with vynyl, cardboard or paper sheets while the sheets of 3/8 to 1/2 inch(9.53 to 12.7 mm) thickness and over 35 feet(10.67 m) long and upto 9 ft. (27.43 dm) wide consist of gypsum reinforced with sisal fibre. By 1963-64 about 12.7 million $m^2$ or 15 million sq. yds[9] of fibrous plaster sheetings were being manufactured annually in Australia. These units are nailed on the timber frames for lining of walls/ceilings and also on the brick veneer construction[11]. The Australian industry has also produced high strength gypsum having crushing strength 12,13 of about 210 kg/$cm^2$ (3000 PSi) as against the normal strength of 126 kg/$cm^2$ (1800 psi) alongwith the other load bearing and structural units. Full sized reinforced precast gypsum walls, prefabricated room units units[10,14] consisting of four complete walls and domed ceiling, poured in one unit to be assembled at the building site are now extensively used in houses built in South Australia, Victoria and New South Wales.

Newzealand also produces gypsum plaster and gypsum board for use in buildings, in modern factories of about 3 million $m^2$ annual[7] capacity, though its natural gypsum resources are scarce. The surplus requirements are met through imports from Australia and England.

The developments are taking place so rapidly today that the given historical appraisal may not be complete /uptodate yet is sufficient to show that gypsum in one form or another has played a major role in the prefabrication industry. The common applications in building industry include fibrous plaster sheetings for internal cladding and false ceilings; plaster boards and allied units; partition walls, building blocks, slabs and panels; light weight aerated products/bloated blocks etc.

In its journey from the deposit to finished cast in construction, gypsum passes through the hands of two sub industries[10]. The first sub-industry gathers gypsum and calcines it to yield the raw material for the casting industry, which fabricates the required elements. In Pakistan a small milling industry is although in somewhat existance, the casting industry has not altogether got underway as yet. Pakistan has[3] vast resources of easily mineable good quality gypsum(Table 1-2).Gyp-

TABLE-1

GYPSUM DEPOSITS IN PAKISTAN

| Sr. No. | SOURCE | | Gypsum & Anhydrite Reserves (Million tonnes) |
|---|---|---|---|
| | Site | District | |
| 1. | Dadu Khel | Mianwali | 62.28 |
| 2. | Village Buri Khel | Mianwali | 2.41 |
| 3. | Village Chihdru | Mianwali | 0.44 |
| 4. | Jabhi | Sargodha | 0.17 |
| 5. | Warcha | Sargodha | 0.45 |
| 6. | Makarach | Jhelum | 0.51 |
| 7. | Dandot | Jhelum | 0.75 |
| 8. | Khewra | Jhelum | 64.77 |
| 9. | Jutana | Jhelum | 1.73 |
| | Total Reserves in Salt range area ..... | | 133.51 |
| II. | Zinda Pir | Dera Ghazi Khan | 67.06 |
| III. | Kohat | Spread over 1800 Sq.Km. | 476.50 |
| IV. | Quetta | Spintangi & Chamalang (depth 15-30 m.) | 7.40 |

Extensive deposits are also known to exist in Dera Ghazi Khan, Khairpur, Hyderabad Divisions and at Sibbi. All these deposits have not yet been comprehensively surveyed.

TABLE-2

PRODUCTION OF NATURAL GYPSUM IN PAKISTAN FROM 1964-77

| Year | Production (tonnes) |
|---|---|
| 1964-65 | 190349 |
| 1965-66 | 115973 |
| 1966-67 | 88081 |
| 1967-68 | 82442 |
| 1968-69 | 103284 |
| 1969-70 | 87781 |
| 1970-71 | 162396 |
| 1971-72 | 165964 |
| 1972-73 | 211910 |
| 1973-74 | 276334 |
| 1974-75 | 296266 |
| 1975-76 | 284175 |
| 1976-77 | 285699 |

Source: 1) Geological Survey of Pakistan. 2) Mineral Development Wing, Industries Deptt. Govt. of Punjab, Lahore

sum is though already an accepted/firmly established building material abroad and was also widely used[4] in the Indian Sub-continent[3,9] before the advent of cement, yet it has neither been given proper weightage nor its potential exploited. With a view to adequately meet with the ever increasing shortage of cement, attempts have been made at the B.R.S. Lahore to revive an interest in gypsum and the traditional methods of building with it that have fallen into disuse with the multiplication of portland cements and to enable at least certain parts of houses to be built without the aid of cement.

## I- EVALUATION OF INDIGENOUS ROCK DEPOSITS/PLASTERS

Representative samples of natural gypsum rock from different quarries and a number of other locations were collected in consultantion with the Punjab Mineral Development Corporation, Directorate of Industries; Geological Survey of Pakistan and Small Industries Corporation alongwith calcined plasters from various commercial manufacturers of Plaster of Paris. The analysis work comprised performance of both physical and chemical tests. The chemical tests were aimed at finding out the amount of calcium sulphate hemihydrate(Plaster of Paris) as its amount in a sample plays an important role in dictating its physical/mechanical properties.

The tests have indicated that Pakistan abounds in high quality gypsum which can be deployed for the manufacture of plaster of Paris on commerical scale (Table-3). Most of the plasters being manufactured at present are also generally fit for building purposes while the others may be easily rendered so. The compositions of some of the locally calcined gypsums are shown in Table-4. The chloride and impurities insoluble in ammonium acetate are slightly more than the required. This is because, gypsum in Pakistan usually occurs alongwith common salt deposits. These constituents may, however, be easily brought well within the required limits provided the rocks are washed thoroughly with drinking water to remove superfluous impurities and other deletereous matter, before crushing or feeding into calcination kettles.

During the coarse of experimental work, it was however, observed that the locally manufactured plasters of Paris were quick setting. It was because of this fact that the use of this material is confined at present to only ceramics and to some extent, the dental industry where quick setting properties are desirable. With a view to make this very stuff also usable in the building industry, efforts were made to control the setting characteristics of these plasters to the specified extents. The setting has been effectively controlled without affecting the physical and mechanical properties by the addition of suitable/ easily available retarding agents(Table-5, Fig. 1).

*TABLE No.-3*

CHEMICAL ANALYSIS OF GYPSUM ROCK SAMPLES AS PER ASTM DESIG: C 471-61

| Sr. No. | Description of Sample | Combined Water $H_2O$ (%) | $CO_3$ (%) | $R_2O_3$ (%) | CaO (%) | MgO (%) | $SiO_2$ (%) | $SO_3$ (%) | Cl (%) | $CaSO_4 2H_2O$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Collected from Kotlakpat Lahore (PSCI) | 18.930 | 2.386 | 0.150 | 30.380 | 1.275 | 2.500 | 44.150 | 0.002 | 73.160 |
| 2. | Collected from Jamshed Mines Grade-I | 20.362 | Nil | 0.450 | 32.552 | 0.190 | 1.200 | 45.065 | 0.002 | 76.093 |
| 3. | Collected from Jamshed Mines Khewra | 16.590 | 0.767 | 0.240 | 33.900 | 0.820 | 1.900 | 45.142 | 0.233 | 71.965 |
| 4. | Black Gypsum Natural Rock Collected from Waqar Ceramics, Lahore | 16.650 | 0.516 | 0.160 | 37.092 | 1.030 | 2.700 | 42.250 | 0.351 | 73.966 |
| 5. | Collected from Waqar Ceramics (Jamshed Mines) | 18.500 | Nil | 0.300 | 32.800 | 0.540 | 2.100 | 45.750 | 0.002 | 74.693 |
| 6. | Collected from Eastern Plaster Industries Gujrat | 19.200 | 1.180 | 0.280 | 30.327 | 1.253 | 1.700 | 45.600 | 0.328 | 73.530 |
| 7. | Collected from Gypsum Factory, Khewra | 12.750 | 1.185 | 0.175 | 33.256 | 0.831 | 1.950 | 49.750 | 0.599 | 68.193 |
| 8. | Collected from Skindar Khan Contractor Khewra Railway Station. | 19.350 | 0.864 | 0.950 | 32.560 | 0.181 | 1.000 | 45.400 | 0.511 | 75.693 |
| 9. | Collected from S.Ijaz Haider Jalalpur Sharif | 18.875 | 0.921 | 0.360 | 31.733 | 0.164 | 1.600 | 45.650 | 0.306 | 74.611 |

NOTE: Requirements of ASTM C471-61:
The Calcium sulphate dihydrate shall not be less than 70% by weight in a gypsum rock fit for producing plaster of Paris.

S.Sibtul Hassan & Ali Muhammad

TABLE-4

COMPOSITIONS* OF SOME LOCALLY CALCINED GYPSUMS

| Serial No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Description | Pakistan Stone Crushing Industries, Kot Lakhpat (S.No.3) | Waqar Ceramics (S.No.6) | Khewra Gypsum Factory (S.No.18) | Eastern Plaster Industries Gujrat (S.No.21) | Pak Trader Mall Road Lahore (S.No (S.No.25) |
| Calcium Oxide (%) | 38.500 | 39.500 | 39.000 | 39.900 | 39.200 |
| Sulphur Trioxide(%) | 54.000 | 53.000 | 53.500 | 53.000 | 53.000 |
| Silicon dioxide(%) | 1.525 | 1.000 | 1.400 | 0.800 | 1.500 |
| Mixed Oxide (%) | 0.320 | 0.250 | 0.300 | 0.650 | 0.350 |
| Megnesium Oxide(%) | 0.453 | 0.500 | 0.451 | 0.850 | 0.450 |
| Carbonate(%) | 1.190 | 1.180 | 1.175 | 1.176 | 1.085 |
| Chloride(%) | 0.292 | 0.0182 | 0.358 | 0.036 | 0.184 |
| Impurities Insolube in ammonium Accetate(%) | 10.725 | 16.525 | 5.475 | 17.625 | 11.65 |
| Combined Water(%) | 3.400 | 4.500 | 3.700 | 2.350 | 4.500 |
| Calcium Sulphate hemihydrate $CaSO_4 - \frac{1}{2}H_2O$ (%) | 51.408 | 68.040 | 55.944 | 35.532 | 54.675 |

(*) Requirements of ASA 43: 1963 & BSS 1191:1967;

Calcium Oxide = shall not be less than two-third of $SO_3$ or shall be more than 32%.
Sulphur Trioxide = shall not be less than 35%.
Chloride = shall not be more than 0.2% when expressed as NaCl.
Impurities in Soluble in ammonium acetate = shall not be more than 10%

TABLE-5

EFFECT OF RETARDERS ON PHYSICAL/MECHANICAL PROPERTIES OF SOME LOCALLY CALCINED GYPSUMS

| Sr.No. Description | | | | Pakistan Stone Crushing Inds. Kotlakhpat (S.No.3) | Waqar Ceramics (S. No.6) | Khewra Gypsum C Fy. (S. No.18) | Eastern Plaster Inds. Gujrat (S.N.21) | Pak Trader Mall Rd. Lahore (S.No.25) |
|---|---|---|---|---|---|---|---|---|
| PHYSICAL PROPERTIES (WITHOUT RETARDERS) | Fineness % Retained | STANDARD AS SPECIFIED BY AS-A/43/1963 | Not more than 1% | 0.5 | 0.4 | 0.5 | 0.3 | 0.25 |
| | Water Requirement 'MIS' | | NIL | 68 | 55 | 71 | 61 | 73 |
| | Initial Setting Times (Mins) | | 20-35 (Mins) | 9.75 | 6.00 | 10.00 | 12.00 | 5.25 |
| | Induction Period (Mins) | | 20-35 (Mins) | 8-9 | 5-6 | 8-9 | 10-11 | 4 |
| | Compressive Strength $Kg/Cm^2$ | | Not Less than 84 | 53.2 | 88.6 | 84.7 | 100.1 | 59.5 |
| PHYSICAL PROPERTIES WITH RETARDERS | Retarder SC. | Initial Setting time (Mins) | | 29 | 25 | 30 | 35 | 34 |
| | | Induction Period (Mins.) | | 25-26 | 20 | 27-28 | 26 | 33 |
| | | Compressive Strength $Kg./Cm^2$ | | 48.16 | 84.7 | 82.6 | 97.3 | 52.5 |
| | | Concentration of retarder (%) | | 0.03 | 0.04 | 0.025 | 0.020 | 0.050 |

## II- MANUFACTURE OF PRECAST GYPSUM UNITS

The casting bed consisted of an evenly finished glazed mosaic surface. It was treated with wax/greese to enable easy release of the cast unit. Metal/wooden mould of appropriate dimensions was placed over the table. The depth of the mould was usually kept about 1.5 mm less than the nominal thickness of the board.

Plaster of Paris obtained from Gypsum Industries Ltd., Khewra with chemical composition and physical properties as shown in Table 4-5, was sprinkled evenly over the water surface rather than water being added to it. The plaster/water ratio was kept as 100 parts of plaster(by weight) in 6-70 parts of water premixed with a small quantity of water soluble retarder(Sodium citrate; about 0.02%). The mixture was then homogenized so as to remove lumps. The requisite amount of the resultant slurry was thereafter poured on to the casting table to completely fill up the mould. The surface was then trowelled off to a smooth finish. After the initial set, the cast was lifted, demouled and kept for subsequent drying at the room temperature. Boards solid as well as hollow(Fig. 2 -3) of approximately following parameters were produced.

TABLE - 6

| DIMENSIONS | SOLID BOARD | HALLOW BOARD |
|---|---|---|
| *Thickness (mm)* | *50.0* | *65* |
| *Width(mm)* | *300.0* | *460* |
| *Length(mm)* | *600.0* | *920* |
| *Diameter of holes(mm)* | - | *35* |
| *Distance between two consective holes(mm)* | - | *35* |
| *Diameter of groove(mm)* | *20.0* | *22.5* |
| *Diameter of tong(mm)* | *17.0* | *20* |
| *Density of gypsum plaster($g/cm^3$).* | *1.2* | *1.2* |
| *Surface* | *Plain,White glazed* | *Plain,White glazed* |
| *Properties* | *Can be bored, Chiselled, Sawn,nailed etc.* | *Can be bored, Chiselled, sawn,nailed etc.* |

Boards of almost any other desired size may also be made in this way. The interlocking tongued and grooved construction of the planks is to ensure joining, fixing and a simple assembly. The verticle cavity running along inside the hallow board may be used for installing conduits.

## CONSTRUCTION OF PARTITION WALL

An experimental room with gypsum partition walls was constructed in the Gypsum Section to provide an Office accommodation. Gypsum battens of 30x10x15 cm size were laid at the floor surface in gypsum mortar along the centre line of the wall. The tongued edges of the precast gypsum solid boards of size 60x30x5 cm. were fixed into the grooves of the bed batten lengthwise all along the periphery of the wall. The empty side spaces were filled with the gypsum mortar. All the boards were fixed in position in the similar manner according to their tongued and grooved construction.

In order to provide a passage way into the room, gypsum pillars of the size 30x10x15 cm. were placed vertically and fixed by putting the board edges into the grooves of the pillar units. Thereafter, the side spaces were duly filled in and finished with the gypsum-mortar. A gypsum lintel of 1.25 m. length was put in gypsum mortar at the top of the door pillars and properly finished off. This lintel is having 2 Nos. 12.7 mm(½") Ø bars at the bottom to take care of the tensile stresses. A wall of 2 m height supported with pillars at base and at spacings of 2 m in between was thus errected. The lay out plan of the partition wall and the details of the units are shown in Figs. 4 and 5.

The cost of these elements and gypsum masonry was worked out and compared with corresponding brick masonry(Appendix-A). This type of wall has been found to cost Rs. 42/- per $m^2$ (Rs. 385/- per hundred sft.) whereas 4½" thick brick masonry wall plastered on both sides is estimated to cost Rs. 61/- per $m^2$ (Rs. 570/- per hundred sft.). The decrease in cost at this stage is not much pronouned yet is more than supplemented by the appreciable decrease in the dead weight of gypsum masonry as compared to brick masonry, which is a very important factor in its favour for use in partition walls. The reduction in dead weight being upto the order of 3.7 times when compared with 4½" brick masonry wall (Appendix-C). The on site labour cost involved in this type of construction shall also be less as compared to brick wall because of the comparatively bigger size of the gypsum board. The construction does not require any sort of curing etc. as well. Moreover, the cost of plaster of Paris is quite high at present due to its manufacture in limited quantity for medical and ceramic purposes only. Gypsum stone at Khewra/Mianwali is available at about Rs. 30/- per tonne while its cost jupms to Rs. 350/-

to Rupees 400/- per tonne after calcining, The calcination of gypsum is done only at about 120-180°C in a much simpler and chaper plant than cement while its current cost is compatiable with the latter. If a demand for this material in the building industry is created and more plants operated to produce it on large scale, it is anticipated that its cost will reduce considerably so as to make it a cheap material for use in the building industry.

## III- GYPSUM FIBROUS PLASTER SHEETING

The gypsum plaster is strong in compression but is comparatively weak in tension and also has low impact strength. The brittle characteristics prevent its effective utilization in structural applications. Efforts were needed to modify the fracture mode of the gypsum plaster from brittle type to quasi-plastic type by incorporating suitable reinforcement. Reference[7,16] to literature led to the use of fibrous and polymer materials. The fibre is to have a high tensile strength and stiffness when wet so that it springs up after it has been pressed down to distribute itself uniformly throughout the plaster. The sisal, polymer, nylon and glass fibres[10,14,17] are most popular abroad and particularly in Australia, owing to their extremely fine threads of considerable tensile properties. The sisal plant grown along the railway tracks and canals (Fig. 6) being toxic, needs special care, conditions, climate and as such it is not generally cultivated on mass scale in Pakistan. Efforts have been made to grow it in a few farms in the Sind Province but the cost appears to be too high. A programme was, therefore, embarked upon to evaluate readily available local fibres(Fig. 7) for reinforcing gypsum units.

Numerous sheets reinforced with chicken net of various hole sizes; jute fibre (1-2%), cut jute(1-2%), sun, hessian, sisal fibres as such and slendered; malmal cloth, old nylon rags and threads; rice husk (1,2 & 3%) by weight), saw dust(1-3%); rice stump, baggasse, sarkanda plants etc. were cast. These sheets were then put to various standard[15] tests. The transverse bending strength was determined by placing a one sq.ft.(929 $Cm^2$) sheet, (sawn from large one; 1.5 x 1m) with its finished surface upward on two parallel supports of length at least equal to the width of the specimen and spaced at 10 in.(25.4 cm) apart centre to centre. The sheets were placed over the parallel supports with incorporated fibre across the loading. A uniformly distributed load was then applied through a ½ in.(12.7 mm) dia steel roller extending across the full width of the specimen (Figs. 8 and 9). The deflection measured at the centre of the specimen and the applied failure load, was used to interpret the reinforcing characteristics of the incorporated materials. Perusal of results given in Table-7 would reveal that the fibres tested may well be classified as regards to their effectivity in the descending order as

imported Australian sisal; Hessian; jute; sisal (local); rice husk; ticken cloth,malmal cloth and cut fibres etc. The local sisal has shown somewhat lesser strength than the Australian one. This is because that whereas the Australian fibres are extracted from the plant in the factory under controlled conditions and thoroughly teased to single threads[10,8] of uniform diameter, the local ones were simply obtained after beating the wetted plant against a soild plateform and with subsequent combing. The fibres thus obtained did neither posses uniform diameter/length, nor were totally devoid of green remains of the plant.

Bending strength of reinforced sheets with hessian, jute and sisal fibres was found well within the limits prescribed by the standard specifications. These sheets can thus be safely used as structural material for partition etc.

MANUFACTURE OF SHEETS

A containing wall to retain the plaster while it is fluid was provided by metal/wooden strips or bars placed around the edges of the casting table. The strips acted as screeding surfaces and determined the thickness of the finished sheets. The strips were usually kept 1.5 mm thiner than the nominal thickness of the sheets. A thin coat of the release agent was applied over the bed of the table and the interiors of the strips. The plaster was gauged to an even consistency free from lumps. A face gauge of unreinforced plaster was then spread to cover the entire surface of the table to an approximate thickness of 1.5 mm and was allowed to just partially set. This was done to keep away the fibres from the surface of the sheet. The requisite amount of teased fibre reinforcement was then distributed evenly over the surface of the face in such a way as to overhang the edges by about 5 cm. The required amount of body plaster was then poured over the fibre, and the fibre was pressed and rolled down until it was thoroughly incorporated in the body plaster. The protruding edges of the fibre were then turned into the sheet to strengthen the edges. After ruling off the sheet, the exposed surface of the cast was smoothed by trowelling. When the plaster had set, the sheet was lifted and allowed to dry in air (Fig. 10). The size of the cast sheets was usually 150 x 100 x 2 cm. These can however be made to almost any desired size.

PARTITION UNIT WITH SHEETS

Gypsum battens of size 10x10x150 Cm were laid in gypsum-mortar at the top of the floor along the longitudinal axis of the wall. These units were screwed at an interval of 30 Cm at the grooveline to give it substantial fixity. A groove of 2 Cm width was dug in the side brick-

TABLE-7

FLEXURAL BEHAVIOUR OF REINFORCED FIBROUS PLASTER SHEETS

| Sr. No. | Fibre | Concentration (%) | Deflection + = at failure (mm) | Load+at failure (Kg) | Remarks* |
|---|---|---|---|---|---|
| 1. | Chicken net(hole size 12-13 m.m.) | 1 Layer | 4.57 | 25.06 | Unfit. |
| 2. | Gypsum unreinforced | - | 0.33 | 21.54 | -do- |
| 3. | Hessian Fibre | 1 | 8.20 | 39.50 | Fit |
| 4. | -do- | 2 | 11.33 | 58.20 | -do- |
| 5. | Jute Cut | 1. | 2.26 | 24.36 | Unfit |
| 6. | -do- | 2 | 4.42 | 21.22 | -do- |
| 7. | -do- | 3 | 3.30 | 26.46 | -do- |
| 8. | Jute Fibre | 1 | 9.01 | 29.79 | Fit |
| 9. | -do- | 2 | 9.52 | 48.97 | -do- |
| 10. | -do- | 3 | 12.44 | 40.90 | -do- |
| 11. | Malmal Cloth | 1 Layer | 0.38 | 27.71 | Unfit |
| 12. | -do- | 2 Layer | 0.45 | 30.56 | Partially fit |
| 13. | Rice Husk | 1 | 0.48 | 65.77 | -do- |
| 14. | -do- | 2 | 0.43 | 64.63 | -do- |
| 15. | -do- | 3 | 0.48 | 65.31 | -do- |
| 16. | Saw Dust | 1 | 0.48 | 27.42 | Unfit |
| 17. | -do- | 2 | 0.45 | 24.48 | -do- |
| 18. | -do- | 3 | 0.48 | 22.00 | -do- |
| 19. | Sisal(Local). @ | 2 | 8.00 | 40.82 | Fit |
| 20. | Sisal(Australian) | 2 | - | 61.87 | -do- |
| 21. | Straw | 2 | 0.55 | 15.47 | Unfit |
| 22. | Ticken Cloth | 1 Layer | 2.54 | 34.47 | Partially fit |

* Requirements as per AS A44:1963 — The maximum proof load of 9.525 m.m. thick sheet, at failure shall not be less than 29.5 Kg. & the deflection measured at the centre of sheet at failure, shall not be less than 6.35 m.m. and more than 19.00 mm.

\+ m.m. x 0.0394 = inch ; Kg x 2.2046 = Lb; @ After Brotchie & Gerda[5]

masonry wall. Thereafter the gypsum sheets of 150x100x2 cm size were put into the groove of bottom units and side spacings filled with the gypsum mortar. Along the vertical edge of the gypsum sheet, steel strips 6 x 2 cm were fixed to the sheets by nailing and the other ends embedded into the groove of masonry wall alongwith finishing off with gypsum-mortar. Similarly all the sheets were fixed in position. At the vertical joints of the sheets gypsum-bracing(10 cm wide and 2 cm thick and of appropriate length) were fixed with screws. This was done to prevent the sagging of the gypsum sheets. In the same pattern, the gypsum sheets were braced at the top level. The details of the units and the construction have been shown in Fig.11.

The analysis of cost of a typical partition wall unit constructed with produced fibrous sheetings has been worked out(Appendix-B). This type of wall has been found out to cost Rs. 31/- per $m^2$ or Rs. 284/- per hundred sft as compared to Rs. 42/- per $m^2$ or Rs. 385/- per 100 Sft. and Rs. 61/- per $m^2$ or Rs. 570/- per hundred Sft. of gypsum board wall and brick masonry wall, respectively. The reduction in dead weight(Appendix-C) is upto about 8 times when compared with half brick masonry wall and upto about 2 times with gypsum board wall. This much reduction in load is quite significant as this load will reduce the size of the beam required for supporting these gypsum partition walls; foundation etc. to a great extent specially in multistoreyed buildings.

## IV AERATED LIGHT WEIGHT PRODUCTS/BLOATED BLOCKS

Aerated gypsum, a light weight cellular material, is an ordinary gypsum plaster into which gas bubbles and a small amount of an air-entaining agent have been introduced in such a manner that when the plaster has set, a unfform cellular product is formed. It is characterised by low unit weight, high porosity, high sound absorpotion, nailability and saw-ability. Its crushing strength depends mainly on its density.

With a view to control the cost of constructing walls either by gypsum boards or the fibrous sheets, efforts were made to produce lighter gypsum products, requiring appreciably lesser plaster compared to solid or hollow units, by making use of cheap indigenous materials. A resinous foaming agent was developed in the laboratory for the purpose. This was admixtured into the plaster-water slurry which was then churnned slowly in a foaming machine. Air bubbles got uniformly entrapped within the slurry in the process which gave a low unit material after setting.

Blocks, slabs and bricks of several sizes with different densities and crushing strengths have successfully been produced(Fig.12) simply adjusting the plaster: water ratio and the concentration of the

foaming agent. A material of as low a density as 0.48 g/cm$^3$(30 lbs/cft) has been successfully produced. The low cost bloated blockes can be used for partition, false ceilings and as insulating units to cut off the heat radiation etc. A demonstration unit is planned to be soon put up with these units.

## FIXING AND JOINTING FIBROUS PLASTER SHEETINGS

Fibrous plaster sheets may be attached[1,11] to the structures by means of nails, organic adhesives or scrim. The scrim is a mixture of plaster and fibre and may be applied to the backs of sheets so as to fasten them to the structural member. In the best work scrim may be used instead of nails. When the scrim has set and the adhesives dried, the gap between sheets and nail holes may be filled with plaster and finished. Plaster thicker in consistency than that used in the production of sheets may be trowelled into the gap and nail holes, after dampening the adjacent sheeting. It may then be allowed to stand. After a suitable period of time, the joint may be scrapped down and more plaster applied. The joint may then be sprinkled with water and polished with a trowel. When the trowelled gypsum in the joints and nail holes has dried, the job may if required be painted.

## ADVANTAGES OF GYPSUM PRODUCTS

1. The ease with which gypsum plaster may be cast, its quick setting and above all the rapidity with which it gains strength combine to make it a useful and interesting building material which should find greater application, especially in drier areas where timber is scarce but gypsum is not. Precast wall units are usually hard enough to be trodden on from 15 to 20 minutes after casting and can be lifted after 25 minutes. For most plasters, the walls are strong enough to take an ordinary house load one hour after casting. Thus, a high rate of production can be obtained from a small factory with limited equipment.

2. Cast gypsum usually has a 'net' expansion on setting so that the danger of shrinkage cracks is almost removed. Cracks which may occur from any cause can be readily repaired.

3. It is a fairly light material. Its density when saturated with water is about 1.5 g/cm$^3$ (or about 95 lbs. cft) and when dry 1.2 to 1.35 g/cm$^3$ (75 to 80 lbs/cft). The handling/transport costs for precast units are thus low.

4. With the use of precast gypsum units, the time required for construction is reduced, thereby reducing the number of man-hours of skilled-on-site labour.

5. The use of gypsum boards and fibrous sheets in wall construction will reduce total load approximately by3.5 to 8 times which will eventually reduce the size of the slab, beam and foundation etc. alongwith the quantity of steel to a great extent especially in multistoreyed buildings.

6. Under conditions of strictest economy, it is possible to obtain a surface finish, straight off the mould, which needs no additional decorative treatment. Similarly when adopted for finishing, the surface of wall and ceiling can be finished smoothly without cracks and scaling, or peeling off. It gives a better finsih with a fine delicate texture without cracks as compared to lime and other plasters.

7. It possesses good thermal insulating and sound absorption properties. Use of gypsum boards in case of buildings to be air conditioned, reduces the load on air-conditioners as these provide an insulating air space between the board and the wall. Gypsum sound absorption boards in place of ordinary plaster for ceiling and walls gives better living comforts to inmates.

8. Gypsum boards are superior to similar materials such as plywood, fibre boards etc. in strength, hardness and other mechanical properties.

9. In addition to the above, it is highly recommended for sound insulated and fire proof walls as it releases water vapours on being heated which has the tendency to inhibit the spread of flame.

Gypsum is, however, somewhat soluble in water to the extent of about 2 gms/litre and therefore may not be used in exposed positions. In the most common use of cast gypsum as load bearing walls of houses, it is protected in Austerlia, by a brick veneer. However, in parts where rainfall[1,10] is less than 25 cm, cast gypsum may be used in exposed positions without any great risk, by adopting such forms of construction which minimize the same, such as the use of wide eaves or a cavity wall built of two leaves each of cast sypsum, the inner being the load bearing unit and the outer serving as a weather protection. Any deterioration of the outer skin may well be reduced by painting, in such a climate. In some parts of Cyprus[3], plaster has been used externally. The periodical renewal needed is counter balanced by its low cost.

## CONCLUSION

The production technique for gypsum plaster as well as precast products is very simple and may be carried out with inexpensive equipment in labour intensive communities like ours. The requisite technical know-how is already available and also the use and application of gypsum has already been established. There is no doubt that as de-

mand for gypsum products is developed, its productivity will surely rise and it may then be possible to cut down the cost of its production which could eventually result in its mass scale utilization in building industry. Even if gypsum has no other merits, its use is bound to make up atleast for a good portion of the demand for cement which has been considered more or less indispensible in the housing sector and to a large extent in the building construction industry as a whole.

## RECOMMENDATIONS

Some how or other gypsum(board as well as sheet) has not been so popular in Pakistan so far. Under the prevailing conditions, it is to take quite some time to build up a sizeable consumer market for this material. It is, therefore, necessary to take some effective steps to popularize its use through product publicity, besides extensive sales compaigns and propoganda/dissemination of the technical information/data on the subject.

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APPENDIX-A

## ANALYSIS OF RATES FOR THE MANUFACTURE OF GYPSUM BOARD/ BLOCKS

I- GYPSUM BOARDS

| | | | |
|---|---|---|---|
| | Size of One board | = 60 x30x5 Cm | |
| | Cubic contents of one board. | = 9000 $Cm^3$ | |
| | Material required for One board; density of gypsum plaster @ 1.2 g/cm3 | = 10.80 Kg. | |
| i) | Cost of Gypsum Plaster for one board 10.80 Kg @ Rs. 350/- per tonne (Available from Allied Stone Crushing Factory Shahdara Lahore on 14.4.1979 with bags). | Rs. | 3.78 |
| ii) | Labour for one board @ 25%(Approx;) | Rs. | 0.95 |
| iii) | Add for depreciation and oiling etc. @ 1% | Rs. | 0.04 |
| | Rate per Unit. Total: | Rs. | 4.77 |
| | Rate per $m^2$. | Rs. | 26.50 |

II- GYPSUM BLOCKS

| | | | |
|---|---|---|---|
| | Size of One block | 30x10x15 Cm | |
| | Cubic contents of one block without groove | 4500 $Cm^3$ | |
| | Cubic contents of groove (5 x 5 x 30) | 750 $Cm^3$ | |
| | Cubic contents of manufactured block | 3750 $Cm^3$ | |
| | Material required for one Block | 4.5 Kg. | |
| i) | Cost of gypsum plaster for One Block | Rs. | 1.58 |
| ii) | Labour for One block @ 25%(Approx) | Rs. | 0.39 |
| iii) | Add for depreciation and oiling etc @ 1% | Rs. | 0.02 |
| | Rate per Unit. | Rs. | 1.99 |
| | Say | Rs. | 2.00 |

APPENDIX-B

ANALYSIS OF RATES FOR THE CONSTRUCTION OF GYPSUM/B.B. MASONRY WALLS OF 3 METRE HEIGHT( MAY/1979)

PART 'A': GYPSUM BOARD WALL — Unit % $m^2$

Length of wall = 2.0 m

I- MATERIALS

Size of Gypsum pannel baord (Cm) =60x30x5

Size of Gypsum pillar block (Cm ) = 30x10x15

| | | |
|---|---|---|
| i) Cost of pannel boards 33 Nos. @ 4.77 each | | Rs. 157.41 |
| ii) Cost of pillar blocks 10 Nos. @ 2.00 each | | Rs. 20.00 |
| iii) Cost of foundation blocks 6 Nos. @ 2.00 each | | Rs. 12.00 |
| iv) Add for gypsum mortar for joints @ 0.6 $m^3$ per 100 $m^2$ (adopted from graph for masonry construction of brick wall section)0.036 $m^3$ or 43.2 Kg. @ Rs. 350/- per tonne. | | Rs. 15.12 |
| | Total: | Rs. 204.53 |
| v) Add for wastage etc.@ 5% | | Rs. 10.23 |
| | Total: | Rs. 214.76 |

II- LABOUR

| | | |
|---|---|---|
| i) Mason 1/2 No. @ Rs.40/- per day=Rs. 20/- )<br>ii) Cooly 1 No. @ Rs.15/- per day = Rs.15/- ) | | Rs. 35.00 |
| | G. Total: | Rs. 249.76 |

Area of wall= 6.0 $m^2$ or 64.85 Sft.

Rate per % $m^2$ ..... Rs.4162.67

Or Rate per % Sft. ..... Rs. 385.14

PART 'B' BRICK MASONRY WALL

Length of wall ( m ) = 2.00
Pillars(Cm) = 22.86x22.86
Size of Wall(Cm) = 200x11.43x300

I- MATERIALS

i) Brick masonry work;(177.14x11.43x300+22.86x 22.86 X 300) = 0.7642 $m^3$ = 27.30 $ft^3$

ii) Plastering area both sides of thickness; (2x200x300+22.86x300+2x5.715x300)=13.03$m^2$or 140.25 sft.