# Gypsum-based fibre-reinforced composites: an alternative to timber

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Investigations have been carried out on the development of natural and glass-fibre-reinforced boards based on gypsum plaster produced by calcining natural as well as by-product gypsum. The characteristics of β-hemihydrate plaster and high-strength water-resistant gypsum binder developed from phosphogypsum and the plasterboards/composites (sisal, coir and glass fibres) are discussed and the use of gypsum boards as an alternative to timber is highlighted.

Keywords: gypsum; fibre-reinforced composites; plasterboard

atural composite material made of cellulosic dded in a matrix of lignin, is one of the important uction materials for house building. The ever construction work demanding more and more ood has not only resulted in the gradual depleource, i.e. forest, but caused an increase in its created an ecological imbalance. According to ate 17 million hectares of global forests were d and converted to other uses in 1987 compared illion hectares in 1981[1]. The worldwide loss of closed forests in 1987 has amounted to 20.4 ctares. Estimates of deforestation vary sub and the true extent is not known, but it is Hence, there is a staunch need for developing alternative materials to wood.

titions, ceiling and wall panelling applications, is used extensively followed by particleboard, estos cement (AC) sheet, hardboard, plaster of panded polystyrene, natural marble, ceramic granite[2].

ywood industry is suffering from the want of rials and part of the required wood is imported. cost coupled with the low availability indicate a in the use of plywood in the future. The plain industry is no longer encouraged by the Indian ent owing to 'asbestosis' problems associated industry. Hence, no further licences are being olystyrene is highly combustible. Gypsum prodsuperior to these materials as they are fire resistaper, possess sound and thermal insulation s and are superior to particleboard in strength kability. Moreover, gypsum products can be cated and are easy to assemble.

e manufacture of gypsum building products, a material popularly known as gypsum plaster or β-hemihydrate is used as the starting material. For the manufacture of gypsum plaster, natural as well as by-product gypsum are calcined in kettles, mechanized pans, rotary kilns or autoclaves. Extensive work has been carried out at the Central Building Research Institute, Roorkee (CBRI), regarding the processing and calcination of by-product phosphogypsum and natural gypsum. Various types of building boards such as fibrous gypsum board and glass-reinforced composites have been developed from the β-hemihydrate plaster. To make gypsum plaster suitable for exterior use, a water-resistant gypsum binder of high strength and low water absorption has been developed from phosphogypsum.

In the present paper, the properties and uses of gypsum sheeting materials like fibre-reinforced gypsum boards, paper-coated boards and gypsum fibreboards have been highlighted. The characteristics of a newly developed water-resistant gypsum binder and its use in glass-reinforced gypsum composites are described. The wood-like properties of gypsum boards suggest their use as an alternative to timber, both for exterior and interior applications.

## Materials and methods

### *Availability of gypsum*

*Natural gypsum.* Indian reserves of natural gypsum are placed at about 1249 million tonnes but the reserves are limited to 286 million tonnes only[3]. The production of mineral gypsum in India and abroad is given in *Table 1*. The bulk of production of gypsum in India of low-grade 70–80% $CaSO_4.2H_2O$, accounting for 86% of the total production, followed by grades 80–85% $CaSO_4.2H_2O$ (7%), 85–90% $CaSO_4.2H_2O$ (6%) and above 90% $CaSO_4.2H_2O$ (1%).

*By-product gypsum.* Besides natural gypsum, about 4.5 million tonnes of phosphogypsum are obtained as a by-product from the phosphatic fertilizer industry. With

ndence to Dr Manjit Singh

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...le 1 Production of mineral gypsum in India and abroad

| ...country | Total production per year (million tonnes) |
|---|---|
| [illegible] | 1.423 |
| ...ujarat | 0.000 34 |
| ...chal Pradesh | 0.0031 |
| ...u and Kashmir | 0.0115 |
| ...sthan | 1.333 |
| ...l Nadu | 0.0670 |
| ...r Pradesh | 0.0086 |
| [illegible] | 84.0 |
| [illegible] | 14.2 |
| [illegible] | 9.0 |
| ...ada | 8.4 |
| [illegible] | 7.2 |
| [illegible] | 5.5 |
| [illegible] | 5.4 |
| [illegible] | 5.0 |
| [illegible] | 3.5 |
| [illegible] | 3.0 |
| ...land | 2.5 |
| ...ico | [illegible] |
| ...er countries | 20.3 |

...reased capacity and utilization of fertilizer plants, ...ailability of phosphogypsum may increase further. ...hogypsum contains impurities of $P_2O_5$, fluoride, ...c matter, undecomposed phosphate rock, quartz ...alis, which are found on the crystal surface, built ...the lattice, or in the interstices of agglomerated ...ls. These impurities adversely affect the workabi... ...etting and strength development of the plasters and ...ts. Consequently, phosphogypsum is being used ...little in the manufacture of cement, ammonium ...e fertilizer and in soil reclamation. Most of the ...hogypsum remains unutilized at present.

...eral processes of purifying phosphogypsum (i.e. ...ng, thermal and chemical treatment[4]) have been ...oped at CBRI. The wet sieving of phosphogypsum ...gh a 150 $\mu m$ sieve was found to be effective in ...cting the impurities of water-soluble and water-...vable $P_2O_5$, fluoride, organic matter and quartz[5]. ...d on this wet sieving process, a pilot plant for the ...cation of phosphogypsum is likely to be established ...BRI in the near future.

...e calcined gypsum plaster and set plaster products ...rming to IS 8272-1984[6], IS 8273-1984[7] and IS ...art 1)-1976[8] were produced from the purified ...m. The properties of these plasters and their prod... ...re shown in *Table 2*. Apart from phosphogypsum, ...t 0.2 million tonnes of marine gypsum and 0.08 ...on tonnes of fluorogypsum are obtained as by-pro... ...s from sea water and the production of hydrofluoric ...espectively[3].

## ...ination of gypsum

...um as such does not possess proper setting and ...ening properties. The industrial utility of gypsum is ...ed to its ability to lose water on heating. Chemi-...y, gypsum is the sulfate of calcium with two mole-...s of water ($CaSO_4.2H_2O$). It contains 79.1% of cal-... sulfate and 20.9% of water. On heating between ...and 180 °C, gypsum loses about 14.7% of water of crystallization in the form of steam, giving the appearance of boiling resulting in the formation of $\beta$-hemihydrate plaster ($CaSO_4.\frac{1}{2}H_2O$) which contains about 6.0% of the remaining water of crystallization. This is called plaster of Paris.

An energy-efficient gypsum calcinator with a capacity of 7.5 tonnes per day has been developed and commercialized by CBRI for making uniform-quality plaster of Paris[9]. The calcinator has a low fuel consumption of about 40 kg of coal ($C_V$ 5500 kcal kg$^{-1}$) per tonne of charge, compared with 200 kg used in the traditional open-pan calcinator, and ensures a higher thermal efficiency of about 80%.

## Fibre-reinforced composites

The internal surfaces of the walls and ceilings of most buildings are finished by applying plaster in one or more coats. In order to reduce the requirement of site labour, the use of building board such as gypsum plasterboard, fibre hardboard and asbestos cement building boards as coverings for the walls and ceilings is increasing steadily. The gypsum products are light, porous, dry and non-brittle with good working and practical properties. They also have specific fire-resisting properties. For these building materials $\beta$-hemihydrate is the starting material which is known for its rapid setting and wide acceptability by plasterers the world over.

Different types of gypsum boards such as gypsum plasterboards, fibrous gypsum plasterboards, gypsum fibreboards, gypsum-bonded particleboards and glass-reinforced gypsum (GRG) are being produced throughout the world. These products are considered as an alternative to timber in view of their similarity to wood. A brief account of these products is given below.

### *Gypsum plasterboard*

Gypsum plasterboards consist of a gypsum plaster core with or without fibre encased in and firmly bonded to strong durable paper liners to form rectangular boards. The paper surface may vary according to the use of the particular type of board and the core may contain additives to impart additional properties. The longitudinal edges are covered by paper and profiled to suit the application of IS 2095-1982[10].

In India gypsum plasterboard, popularly known as gypboard, is now produced by India Gypsum Ltd at their factory in Jind (Haryana). It is a joint venture company promoted by Hyderabad (formerly Hyderabad Asbestos Cements Products Ltd) and BPB Industries Plc, UK, Europe's largest manufacturer of gypsum plasterboards. India Gypsum has packages of products and systems for the purposes of sound and durable wall linings, partitions or as claddings to structural steel columns and beams and suspended ceilings, assuring speed, ease of fixing and low overall costs. The boards may be cut, sawn and can be fixed by nailing, screwing or sticking with gypsum base or other adhesives. They may also be inserted in lay in grids and/or secured by clips. *Table 3* gives the properties of gypboard.

Gypsum plasterboards are also further processed into

...perties of calcined phosphogypsum and its products

| ...product | Density (g cm⁻³) | Compressive strength (N mm⁻²) | Transverse load (N) | Thermal conductivity (kcal m⁻¹ h⁻¹ °C⁻¹) |
|---|---|---|---|---|
| ...hydrate | 1.0–1.1 | 8.1–13.1 | – | – |
| ...hydrate | 1.3–1.4 | 22–30.0 | – | – |
| ...ydrite | 1.6–1.7 | 30–33.3 | – | – |
| ...plasterboard | 1.0–1.1 | – | 350–500 | 0.14–0.17 |
| ...g blocks | 0.9–0.95 | 2.5–3.5 | – | 0.13–0.15 |
| ...l tiles | 0.42–0.43 | 1.5–2.0 | – | – |

...perties of gypboard

| | Square | Tapered | Bevelled | Rounded |
|---|---|---|---|---|
| ...(mm) | 9.5 | 12.5 | 15.0, 19.0 | 23.0, 25.0 |
| ...m) | 619 | 914 | 1219 | |
| ...m) | 610 | 1220 | 2438 | |
| ...g m⁻²) | 8.0 (9.5 mm) | 10.5 (12.5 mm) | 12.80 (15.0 mm) | 20.0 (23.0 mm) |
| ...sistance (m² K⁻¹ W⁻¹) | 0.06 (9.5 mm) | 0.08 (12.5 mm) | 0.09 (15.0 mm) | |
| ...ction | Fire propagation index of performance $a(I)$ not exceeding 12 and a subindex ($i$) not exceeding 6 (both sides), class I (both sides). When each side tested separately to BS 476: Part 6, 1981[11]. Surface spread of flame when tested to BS 476: Part 7, 1971[12] | | | |

...or special applications such as lightweight lami...nels, with expanded polystyrene or polyureth...e middle layer (insulating boards). Multilayer ...ards with a surface finish (e.g. with decorative ...lm or coating or with aluminium foil) to prevent ...apour transmission are also available.

### *...ypsum plasterboard*

...gypsum plasterboards are very popular in ...ountries. These are 12 mm thick boards of set ...plaster reinforced with organic fibre. Normal ...ns of boards are 120 × 60 cm. The board is ...for its light weight, thermal insulation and fire ...e. These boards are produced by sandwiching ...ed sisal fibres in between two layers of gypsum ...lurry, followed by hardening, demoulding and ...ying in the open sun or in driers[13].

...g various lignocellulosic fibres sisal, coconut ...stha and bhabhar have been studied for the ...ment of gypsum plaster. The major chemical ...ts of these fibres are cellulose and lignin. The ...of these fibres in continuous form as well as cut ...s studied on the properties of gypsum plaster ...from the purified phosphogypsum. The rela... between transverse bending load and fibre ...s shown in *Figure 1*. The effect of the part ...ent of sisal fibre by coconut coir, mestha and ...fibres on the transverse bending load of gypsum ...plotted in *Figure 2*.

...be seen that transverse strength increases with ...se in fibre content. At a 2.5% level of fibre, ...m transverse strength is attained both with the ...as well as the mixture of sisal and coconut coir ...e proportion of 80:20 by weight respectively. ...of combined fibre have already been incorpor... IS 8273-1984[7] for commercial applications.

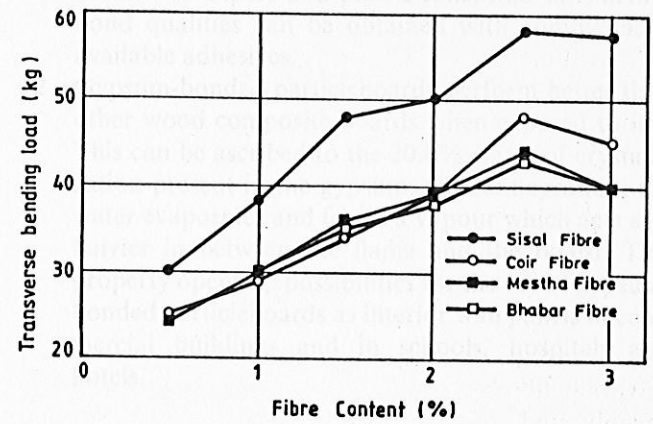



**Figure 1** Effect of fibre content on transverse bending load

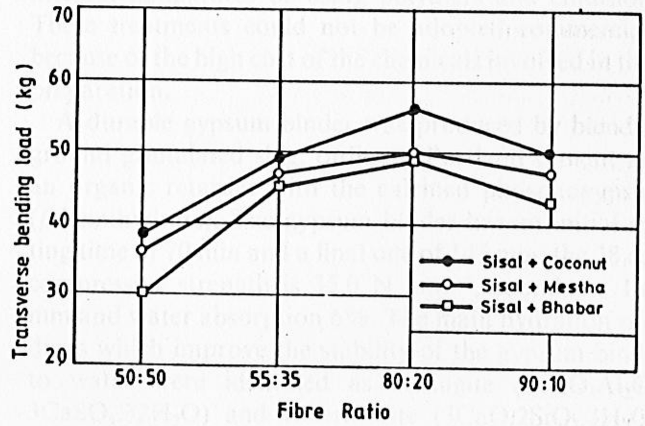
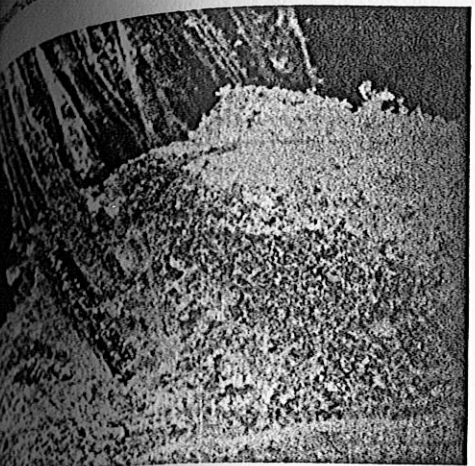



**Figure 2** Effect of mixture of different fibres on transverse bending load



...3 Microstructure of set gypsum plaster reinforced with sisal (...250)

...3 shows the microstructure of gypsum plaster ...ed with sisal fibre. It can be seen that the fibres ...low and have a rough surface. Sisal fibres in ...n plaster make intermittent contact with the ...through recrystallized gypsum crystals.

...thermal conductivity ($K$) of fibrous gypsum plas...d is 0.14–0.17 kcal $m^{-1}$ $h^{-1}$ $°C^{-1}$ compared with ...al $m^{-1}$ $h^{-1}$ $°C^{-1}$ for 6 mm thick asbestos cement ...ith a density of 1700–1800 kg $m^{-3}$. The grading ...of fire resistance of 12 mm thick plasterboard is 30 ...s and it is far superior to fibre building boards in ...spect. The boards are likely to suffer losses in ...h and structural properties as they are exposed to ...ent dampness. Hence, these boards are recom...d for internal applications only.

*...n fibreboard*

...m fibreboard (GFB) is a new building material ...applicable at present for dry, interior building ... The basic materials for the manufacture of GFB are ...urity gypsum (85% $CaSO_4.2H_2O$) and waste ... In these boards, the cellulosic fibres produced ...he waste paper are intimately embedded in the ...m mass. By the homogeneous distribution ...hout the complete board, the cellulosic fibres ...e a reinforcement and bind the gypsum composite ...er and make it elastic. Sometimes a surface coat...atment is applied to the board which increases its ...ical strength significantly. Siemkel Kemp[14], a ...n company, has brought the manufacturing pro... industrial maturity. At the beginning of industrial ...tion, the dimensions of the boards were 1500 × ... 15 mm and these were later increased to 6000 × ... 10 mm. A GFB plant (Wurtex(Process)) with a ...ity of 1575 $m^2$ $h^{-1}$ of board of 10 mm thickness is ...g at present in the Netherlands[15].

... is water and fire resistant and possesses excellent ...d insulation properties. Laminated GFB with plastic ...tive sheets and wood veneer can be produced. ...e boards can be used for partition walls inside large ...s and multistoreyed buildings. GFB is not available ...ndia at present but the Bureau of Indian Standards has taken the initiative to formulate a standard specification of these boards for the consumer in the near future.

*Gypsum-bonded particleboard*

Gypsum-bonded particleboard is being produced in Scandinavian[16] plants that utilize the semi-dry process developed by Kossatz[17]. In the conventional manufacturing processes of gypsum-bonded building boards, gypsum plaster is utilized in a highly viscous or liquid state (water/gypsum ratio 0.7 to 0.9). Theoretically a water/gypsum ratio in between 0.15 and 0.19 is sufficient to obtain the complete reaction of hemihydrate to dihydrate. In this process the wood furnish (flakes, particles or fibres) provides sufficient moisture for the binder to set. The properties of gypsum-bonded particleboards produced by the semi-dry process are comparable with or superior to gypsum-bonded board products, such as plasterboard and gypsum fibreboards (*Table 4*).

## End-use characteristics and applications for gypsum

*Bonded particleboards*

1. Gypsum-bonded particleboards provide a surface for a variety of surface systems (e.g. wood veneers, decorative papers and plastic foils) and satisfactory bond qualities can be obtained with commercially available adhesives.
2. Gypsum-bonded particleboards perform better than other wood composite boards when exposed to fire. This can be ascribed to the 20.0% water of crystallization present in the gypsum. On conflagration, the water evaporates and forms a vapour which acts as a barrier in between the flame and the board. This property opens up possibilities for the use of gypsum-bonded particleboards as interior wall panels in commercial buildings and in schools, hospitals and hotels.

*Water-resistant gypsum binder and its use in GRG*

It is well known that gypsum plaster is a cheap binder but its use is limited to internal applications on account of its poor performance with water. Attempts have been made to make gypsum plaster partially or fully water resistant[18] by applying surface coatings, immersing in aqueous solutions of $Na_2CO_3$, $H_3PO_4$, or $Na_3PO_4$, using integral admixtures or using polymers and emulsions. These treatments could not be adopted commercially because of the high cost of the chemicals involved in their preparation.

A durable gypsum binder was produced by blending ground granulated slag, ordinary Portland cement and an organic retarder with the calcined phosphogypsum ($\beta$-hemihydrate). The gypsum binder has an initial setting time of 70 min and a final one of 145 min; the 28 day compressive strength is 35.0 N $mm^{-2}$, soundness 1.60 mm and water absorption 6%. The main hydration products which improve the stability of the gypsum binder to water were identified as ettringite ($3CaO.Al_2O_3.3CaSO_4.32H_2O$) and tobermorite ($3CaO.2SiO_2.3H_2O$). The binder possesses good water resistance compared with plain plaster[19].

...perties of GRG binder composites and some conventional building materials

| | Property | | | | |
|---|---|---|---|---|---|
| | Bulk density (g cm⁻³) | Flexural strength (N mm⁻²) | Impact strength (N mm mm⁻²) | Water absorption (%) | Swelling (24 h) |
| ...de gypsum | 1.2–1.3 | 4–5 | 1.0 | 35 | 1.0 |
| ...ed gypsum | 1.3–1.4 | 7–10 | 1.5 | 32 | 0.9 |
| ...mercial) | 1.6–1.8 | 15–30 | 12–20 | 30 | 0.5 |
| ...(CBRI) | 1.5–1.6 | 20–25 | 16–18 | 16 | 0.4 |
| ...bonded particleboard | 1.1–1.2 | 6–10 | – | – | 2.5 |
| ...plasterboard | 0.8–0.9 | 3–8 | – | 35 | 2.0 |
| ...fibreboard | 1.1–1.3 | 5–8 | – | – | 2.0 |
| ...board | 0.8–2.1 | 14 | 4.5 | 70 | 26 |
| ...cement | 2.1 | 18–23 | 2.0 | – | 0.60 |
| ...forced cement (GRC) | 2.1 | 30–50 | 15–30 | – | – |
| ...bonded particleboard | 1.1–1.3 | 9–15 | – | – | 2.0 |
| ...resin-bonded particleboard | 0.65–0.75 | 12–24 | – | – | 11–15 |
| ...board | 0.9–1.15 | 48–49 | – | 2.2 | 2.4 |
| ...particleboard | 0.8–0.83 | 12–13 | – | 16 | 13.5–14.5 |

## ...forced gypsum binder composites

...plaster, like other inorganic cements, is strong ...ession but weak in tension and has low impact ... Its brittle properties prevent the effective utili... high compressive strength in structural appli... It has been reported that a gypsum composite of ...act and improved tensile strength can be pro... reinforcing E-type glass fibre into the gypsum ...ing suitable fabrication techniques[20]. The use of ...e considerably improves the fire resistance of ...plasterboards.

...tability of gypsum binder was examined for the ...ion of glass-reinforced binder composites ... The composites were produced by a spray suc...hnique using chopped glass fibre (4%, 5 mm ...with a gypsum binder–water slurry. The proper... 28 day cured GRGB boards are shown in *Table 4* ...th other building materials.

...urability of gypsum binder composites was ... by immersing the gypsum composites in water ...eriod of 28 days. After 3 days of immersion ... binder composites have a much lower water ...ion (17.0%) than the composite based on plain ...plaster (35%), indicating the better water resis... the former compared with the latter. The effect ...ate wetting and drying and heating and cooling ... 27–60 °C on gypsum binder composites has ...orted elsewhere[21].

...has some of the properties of timber and can be ...illed, screwed and nailed. It can also be polished ... like wood but with almost identical mechanical ...es in all directions in contrast to timber which is ...ch weaker across the fibre direction. As a result ...ider and thinner GRG boards may be produced ...ed with timber panels, bringing substantial sav...osts. GRG can be used in door panels, structural ...s, cupboards, furniture, etc.

## ...ions

1. ...rous gypsum plasterboards of comparable ...ngth with boards produced with plain sisal fibres can be produced by using sisal and coconut coir fibres (80:20 parts by weight).
2. GRG boards of higher strength and better water resistance can be produced by reinforcing gypsum binder with glass fibres.
3. The use of newly developed water-resistant gypsum binder from phosphogypsum by-product would be an asset for all types of gypsum boards. The water-resistant gypsum binder will definitely increase its scope of utilization in GRG sheets, particularly in exposed applications. The production of gypsum binder from industrial by-products will thus help in disposal and pollution abatement.
4. The use of gypsum boards will conserve scarce wood and enhance the national economy.

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