# Thermal characterization and strength properties of concrete cool roof slab panels integrated with glass wool, rock wool, silica fume and graphene oxide

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**Abstract.** Buildings consume a large share of the energy used for indoor climate control, which raises greenhouse gas emissions and intensifies the urban heat island effect. Improving the thermal performance of roofing elements without reducing their strength is an important goal for sustainable construction. This study evaluates the heat transfer rate, thermal resistance and compressive strength of M20 grade concrete cool roof slab panels made with glass wool and rock wool as insulating materials, silica fume as a partial cement replacement, and graphene oxide as a nano additive. The insulating materials were used in peeled form and as one inch and two-inch-thick pads. Thirty-six panels of size 200 mm x 200 mm x 100 mm were cast and tested. Glass wool panels showed a lower heat transfer rate and lower thermal conductivity than rock wool panels. The top surface temperature dropped by about 15 °C for glass wool panels and about 10 °C for rock wool panels, relative to the control. The combined use of silica fume and graphene oxide gave the highest compressive strength, with glass wool outperforming rock wool. Glass wool with silica fume and graphene oxide suits energy efficient cool roof applications.

**Keywords:** thermal resistance; thermal conductivity; heat transfer rate; glass wool; rock wool; compressive strength; graphene oxide; cool roof.

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# 1 Introduction

The thermal properties of the materials used in external walls and roofs strongly affect the surface temperature of a building and the heat that flows through it. Insulation reduces this heat flow, lowers the demand for heating and cooling, and keeps indoor temperatures more stable. Globally, heating, ventilation and air conditioning systems consume about 15% to 20% of total electricity, and this consumption is a major source of greenhouse gas emissions and a contributor to the urban heat island effect. Reducing the energy used for space conditioning is therefore central to sustainable construction, which aims to limit resource depletion, improve infrastructure resilience and reduce carbon output.

Mineral wool insulation, in the form of rock wool and glass wool, is widely used to control heat and fire in construction. In fire tests on fibre reinforced polymer reinforced concrete elements, rock wool limited the transmitted temperature to about 13% of the applied change, while glass wool and red drywall allowed about 22% and 26 % respectively, which shows that the type of insulation influences thermal protection more than the concrete strength [1]. Rock wool fibres have also been used to reinforce recycled aggregate hot asphalt mixtures, where a fibre content of 1.5% gave the highest tensile strength ratio and the best moisture resistance [2]. Waste glass wool and mineral wool fibres recovered from expired insulation reduced the compressive strength of concrete but improved its tensile strength and freeze thaw resistance, although an excess of mineral wool reduced chloride penetration resistance [3]. Mineral wool and rice straw fibres lowered the thermal conductivity of cement mortar without a loss of mechanical properties [4], and glass wool residue used as a recycled admixture improved the flexural and compressive strength of Portland cement composites [5]. Comparative studies of rock wool against other insulators in concrete blocks have supported the reuse of such waste for better energy efficiency [6]. Related work on fire safe construction has also examined insulation choices for structural floors and for dwellings in wildfire prone areas [7].

Graphene based additives have attracted attention for improving the mechanical and thermal behaviour of cementitious materials. Graphene oxide added at 0.08 % by weight of cement improved the compressive strength, indirect tensile strength and abrasion resistance of concrete by about 21%, 12% and 23 % respectively at 28 days [8]. In mortar tested at high strain rates, graphene contents of 0.05 and 0.01 % raised the compressive and split tensile strengths by about 30% and 9.5 %, and microscopy showed that the graphene filled pores and restricted crack growth [9]. Reviews of graphene concrete report that small additions can produce large gains in compressive strength, flexural strength and elastic modulus, together with potential reductions in carbon emissions [10]. Graphene nanoplatelets have improved the strength, load capacity and ductility of reinforced concrete beams [11, 12], and graphene oxide has been shown to raise both the strength and the thermal insulation of cement mortar composites, with an optimum near 0.05% [13]. Graphene oxide has also been used as a thermally conducting filler in phase change materials, where it increased thermal conductivity and diffusivity [14,15].

The reviewed studies show that insulating fibres, silica fume and graphene oxide have each been used to improve either the thermal or the mechanical performance of cementitious materials. However, their combined use in concrete cool roof slab panels, where the aim is to reduce heat transfer while keeping adequate strength, has received little attention. In particular, the effect of the form and thickness of glass wool and rock wool, used together with silica fume and graphene oxide, on both the heat transfer rate and the compressive strength of roof panels has not been reported.

### 1.1 Research significance and objectives

This study aims to improve the thermal performance and strength of M20 grade concrete cool roof slab panels by combining insulating materials with an industrial by product and a nano additive. The specific objectives are to measure the heat transfer rate and thermal resistance of panels made with glass wool and rock wool in peeled and pad forms, to assess the effect of silica fume and graphene oxide on the compressive strength of these panels, and to compare glass wool and rock wool for cool roof applications. The outcome supports energy efficient roofing that lowers cooling demand and the associated carbon emissions.

## 2 Materials

### 2.1 Description of materials

Silica fume is a highly reactive pozzolanic material made of ultrafine amorphous silicon dioxide particles with an average size of about 0.1 to 0.3 micrometres and a high specific surface area of about 15,000 to 30,000 $m^2$/kg. It improves compressive strength and durability and reduces porosity by densifying the cement matrix.

Rock wool is produced by melting basalt and other minerals above 1,600 degrees Celsius and spinning the melt into fine fibres. It has a density of about 40 to 200 kg/$m^3$ and a thermal conductivity of about 0.033 to 0.040 W/(m.K). It is fire resistant, with a melting point above 1,000 degrees Celsius, and provides good thermal and acoustic insulation.

Glass wool consists of fine interlaced glass fibres with diameters of about 2 to 6 micrometres. It has a low thermal conductivity of about 0.03 to 0.04 W/(m.K) and high sound absorption. It is chemically stable, non-combustible and resistant to moisture and biological attack.

Graphene oxide is a two-dimensional material obtained by the chemical oxidation of graphite. It carries oxygen groups such as hydroxyl, epoxy and carboxyl, which give it good dispersibility in water. It has a high specific surface area and offers high mechanical strength and thermal stability.

### 2.2 Properties of materials

Ordinary Portland cement of grade 53, with a specific gravity of 3.15, was used for the M20 grade concrete. Silica fume was used as a partial replacement for cement. The physical and chemical properties of the cement conformed to IS 4031 (Part 4). The coarse and fine aggregates were obtained from local sources and satisfied IS 383 (2016). Rock wool and glass wool were used as insulating materials in the slab panels, in both peeled form and pad form. Potable tap water was used for mixing. The measured properties of rock wool, glass wool and graphene oxide are given in Table 1.

**Table 1.** Properties of the insulating materials and graphene oxide.

| **Material** | **Density (kg/m$^3$)** | **Thermal conductivity (W/(m.K))** | **Melting point (deg C)** | **Diameter (um)** | **Tensile strength (MPa)** | **Flexural strength (MPa)** | **Compressive strength (MPa)** | **Elastic modulus (GPa)** |
|---|---|---|---|---|---|---|---|---|
| Rock wool | 200 | 0.044 | 1000 | 10 | 4 | 6 | 2 | 1 |
| Glass wool | 150 | 0.0372 | 1000 | 20 | 4 | 3 | 0.2 | 0.4 |
| Graphene oxide | 1800 | 0.6 | 3600 | 5 | 14 | 11 | 68 | 33.2 |

# 3 Experimental methodology

## 3.1 Mix proportions and casting of slab panels

The concrete mix was designed for M20 grade with a nominal proportion of 1:1.5:3, following IS 10262 (2009). Thirty-six slab panels of size 200 mm x 200 mm x 100 mm were cast in different combinations of cement, fine aggregate, coarse aggregate, water, silica fume and graphene oxide, with glass wool or rock wool as the insulating layer. The panel size was scaled to the internal chamber of the radiation apparatus used for thermal testing. Silica fume was used as a partial replacement for cement, and graphene oxide was added by weight of cement with a superplasticiser to aid dispersion. The insulating materials were placed in the panels in peeled form and as one inch and two-inch-thick pads. The mix proportions are given in Table 2, and the specimen designations are listed in Table 3. The cast panels before testing are shown in Fig. 1.

**Table 2.** Mix proportions of the M20 concrete

| Ingredient | Quantity per cubic metre |
|---|---|
| Cement (OPC 53 grade) | 382.5 kg/m$^3$ |
| Silica fume | 42.5 |
| Fine aggregate | 637.5 kg/m$^3$ |
| Coarse aggregate | 1275 kg/m$^3$ |
| Water | 186kg/m$^3$ |
| Water to binder ratio | 178.5liters |
| Graphene oxide | 0.01245 (i.e., 0.03% weight of binder) |
| Superplasticiser | 4.25 |

**Table 3.** Specimen designations

| Insulation | Form and thickness | Silica fume | Graphene oxide |
|---|---|---|---|
| Reference (none) | Not applicable | With and without | With and without |
| Glass wool | Peeled | With and without | With and without |
| Glass wool | Pad: one and two inches | With and without | With and without |
| Rock wool | Peeled | With and without | With and without |
| Rock wool | Pad: one and two inches | With and without | With and without |


**Fig. 1.** Concrete cool roof slab panels after casting.

### 3.2 Thermal resistance testing

A radiation chamber with an upper and a lower compartment was fabricated for the thermal tests, as shown in Fig. 2. The upper compartment held four thermocouples to record the air temperature and one additional thermocouple to record the top surface temperature of the specimen. The lower compartment held one thermometer for the air temperature. The specimen rested on a wooden plank that separated the two compartments and prevented heat from bypassing the specimen. Heat was supplied by a 500 W halogen lamp placed in the upper compartment. The temperature in the upper compartment was raised gradually until a steady state was reached in both compartments, and the air temperatures were recorded at intervals of one minute. Once steady state was reached, the top surface temperature in the upper compartment and the bottom surface temperature in the lower compartment were measured within 30 seconds using an infrared gun. From these surface temperatures, the heat transfer rate, thermal resistance and thermal conductivity of each panel were obtained using Eq. (1).

$$Q = (T_1 - T_2) / R_{th} \quad (1)$$

where $R_{th} = L/(K A)$ is the thermal resistance of the specimen, $K$ is the thermal conductivity in W/(m.K), $Q$ is the heat transfer rate in W, $L$ is the specimen thickness in m, $A$ is the cross-sectional area in m$^2$, and $T_1$ and $T_2$ are the top and bottom surface temperatures of the specimen.

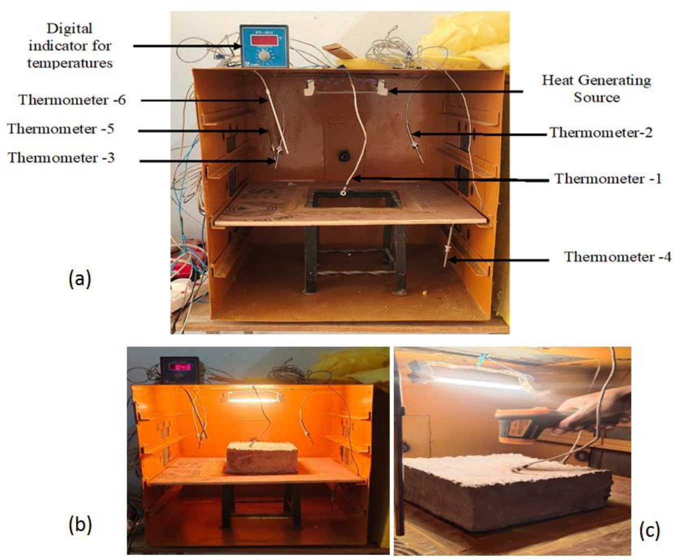


**Fig. 2.** (a) Radiation chamber with thermocouples, (b) specimen exposed to radiation heat, and (c) measurement of specimen surface temperature using an infrared gun.

### 3.3 Compressive strength testing

After the thermal tests, the slab panels were tested under uniaxial compression in a computerised compression testing machine. The failure load was recorded for each panel, and the compressive strength was calculated as the failure load divided by the loaded area. The results are presented in Section 4.

# 4 Results and discussion

The thirty-six cool roof slab panels were tested for compressive strength, heat transfer rate and thermal resistance, with and without silica fume, graphene oxide and the insulating materials. The results are presented in Fig. 3 to Fig. 6.

## 4.1 Compressive strength

Fig. 3 shows the compressive strength of panels made with peeled glass wool and rock wool, with and without silica fume and graphene oxide. The panels containing silica fume and graphene oxide showed a clear increase in compressive strength compared with the reference panel. This increase is attributed to the improved interaction of graphene oxide and silica fume with the insulating material and the surrounding concrete matrix, which produces a denser microstructure.

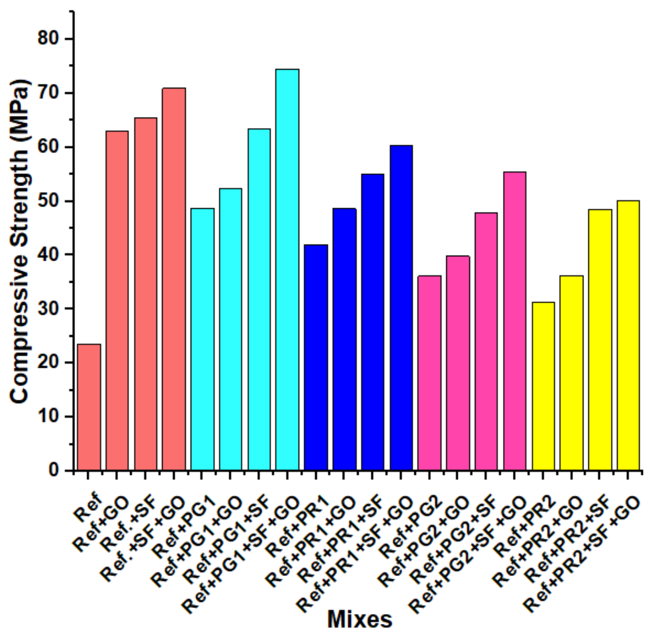


**Fig. 3.** Compressive strength of peeled glass wool and rock wool panels, with and without silica fume and graphene oxide.

Fig. 4 shows the compressive strength of panels made with glass wool and rock wool pads. For the pad panels, the change in compressive strength was small, except for the reference panel containing silica fume and graphene oxide, which showed a marked increase. This behaviour is again linked to the improved interaction between graphene oxide, silica fume and the concrete matrix in the absence of an insulating pad that interrupts the matrix.

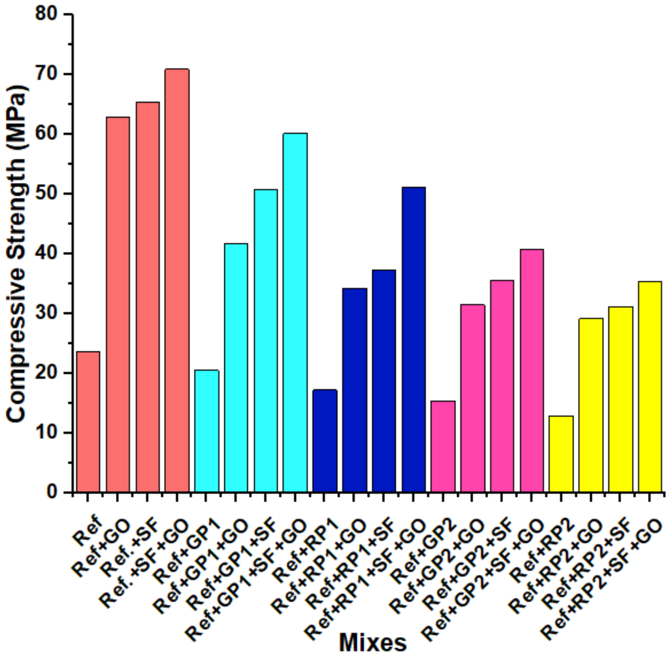


**Fig. 4.** Compressive strength of glass wool and rock wool pad panels, with and without silica fume and graphene oxide.

### 4.2 Heat transfer rate

Fig. 5 shows the heat transfer rate of the panels. The addition of glass wool and rock wool pads strongly reduced the heat transfer rate compared with the reference panel. The one inch and two-inch glass wool pad panels without graphene oxide gave heat transfer reductions of about 92.50% and 94.44% respectively. Adding graphene oxide raised the heat transfer rate of these glass wool pad panels by about 16.53% and 24.93%, which is attributed to the higher conductivity of the concrete after graphene oxide is added. The one inch and two-inch rock wool pad panels without graphene oxide gave reductions of about 95.03% and 96.14% respectively, and the corresponding increase after adding graphene oxide should be reported from the measured values for rock wool. Overall, the glass wool panels showed a lower heat transfer rate than the rock wool panels, which is consistent with the lower thermal conductivity of glass wool.

When silica fume was also present, the one inch and two-inch glass wool pad panels without graphene oxide gave reductions of about 90.48% and 91.58% and adding graphene oxide and silica fume raised the heat transfer rate by about 6.99% and 3.45%. The one inch and two-inch rock wool pad panels gave reductions of about 92.23% and 93.31%, with increases of about 10.37% and 12.0% after adding graphene oxide and silica fume. As before, the glass wool panels transferred less heat than the rock wool panels because of the lower thermal conductivity of glass wool.

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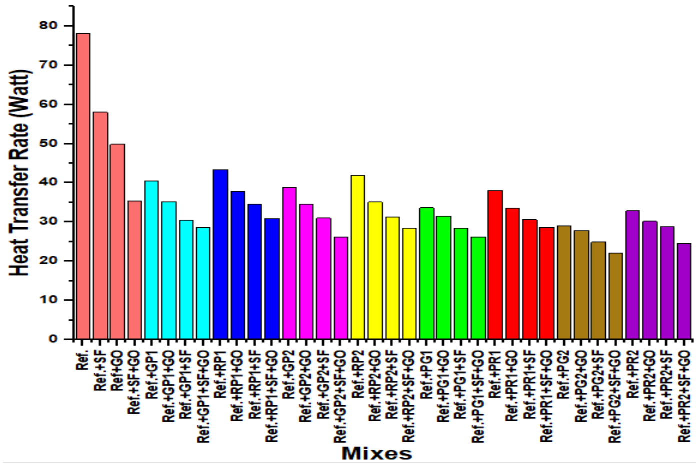


**Fig. 5.** Heat transfer rate of the slab panels, with and without graphene oxide.

### 4.3 Thermal resistance

Fig. 6 shows the thermal resistance of the panels, which follows the opposite trend to the heat transfer rate. The glass wool panels gave a higher thermal resistance than the rock wool panels, and the resistance decreased when graphene oxide was added because of the increased conductivity of the concrete. The measured thermal resistance and thermal conductivity values obtained from Eq. (1) should be tabulated here to support the trend shown in Fig. 6.

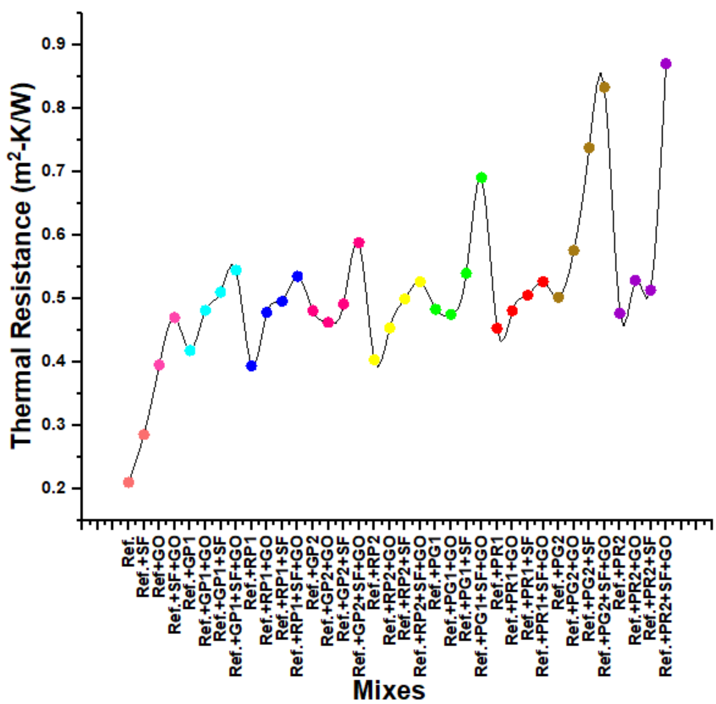


**Fig. 6.** Thermal resistance of the slab panels, with and without graphene oxide.

## 5 Conclusions

The thermal and strength behaviour of concrete cool roof slab panels made with glass wool, rock wool, silica fume and graphene oxide was studied through tests on thirty-six panels. The main conclusions are as follows.

1. Glass wool panels transferred heat more slowly than rock wool panels because of the lower thermal conductivity of glass wool. Glass wool is therefore the more effective insulator and can reduce the cooling energy demand of a roof.
2. The top surface temperature dropped by about 15 ºC for glass wool panels and by about 10 ºC for rock wool panels, compared with the control panel.
3. The combined use of silica fume and graphene oxide gave the highest compressive strength, and glass wool panels reached a higher compressive strength than rock wool panels for the same additions. The higher strength improves durability and reduces maintenance.
4. Adding graphene oxide slightly increased the heat transfer rate because it raises the conductivity of the concrete, so the graphene oxide dosage should be selected to balance strength and thermal performance.

The higher compressive strength of the glass wool panels may be explained by better interlocking of the glass wool within the concrete matrix, a more favourable interaction between the glass wool and the cement paste, and the densifying effect of silica fume and graphene oxide. These factors together support the use of glass wool with silica fume and graphene oxide for energy efficient cool roof panels.

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