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Research Article

Development and study of false ceiling panels using pumice and steel square mesh-case of Ethiopia

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Abstract
In Ethiopia, the false ceiling is done using plaster of Paris (POP), timber and cardboard sheet. POP and timber false ceiling materials are not affordable to the middle- and lower-income group people due to its high cost. Hence, this research objective is to develop a false ceiling panel by using locally available materials such as cement, pumice, metal square mesh, and edible oil as an air-entraining agent. The particle distribution of aggregate used is in the ratio of 70:30. The aggregate retained on sieve size 2.36 mm - 300 µm and passing through finer particles on 300 µm was used to prepare the panels. Total nine slabs 250×250×30 mm and three beams of 250×250×30 mm was casted to study the properties of flexural strength, water absorption, density, fire resistance, and screwing effect. To enhance the production of panels and meets its demands to the public, panels were tested for 14 days instead of 28 days as per the standard requirement. According to the results obtained, it is found that the densities of the panels vary between 1050 kg/m3 and 1070 kg/m3, the percentage of water absorption ranges between 14.6 and 18.73%, and the flexural strength is zero are obtained respectively. The samples are found to be better at fire resistance for 1 hours in an uncontrolled temperature. In addition, the screwing samples did not show any cracking during testing. As the panels are good at fire resistance, they can also be installed in kitchens at residential, hotels, commercial and other public buildings.

Keywords
False ceiling panels, Pumice, Edible oil, Square mesh, Ethiopia.

1.Introduction
False slab is the underside of the sloped roof truss, also known as false ceiling (FC), suspended ceiling, grid ceiling, drop ceiling (DC). These FC is used for both public and commercial applications within a room. These FC enhances the aesthetic of the interiors of the building and also reduces the volume of the room while in the use of air conditioning (AC). The reduction of ceiling height has its advantage with keeping rooms in cooler at the summer up to 16^0C and saves electric bill up to 13%, but it's not much effective in movement for ventilation system [1−3]. The major challenging in ceiling panel is to reduce the weight and enhance the acoustic effect.

In the past, several studies were done on FC panels using different materials such as banana fibers [4], natural sponge fibers, wool fibers [5], polyvinyl acetate[6], sawdust [7], rise husk [7], low density polyethylene, polycarbonate plastics, Palm Kernel Shell [8, 7], egg shell[9], plaster of Paris (POP) ($CaSO_4$ 0.5%H_2O), gypsum board ($CaSO_4$ 0.2% H_2O), wood, plastic, fiber glass [10], thermocol [11], polyester fiber[12, 11], acrylic and polyvinyl chloride (PVC) [6, 13, 14]. Use of wood as ceiling panel has a drawback on moisture absorption due to change in weather condition [15].

In most of the countries, gypsum board and POP are used due to its ease in handling and can be molded into customizing shape and design as per the requirement of the clients [16]. The recent trend has started using of a polycarbonate plastic material due

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to its low cost and reduced in weight and easy to fix even for the long span [17]. The sloped roofs have its own benefits, i.e., low cost in construction and to ease of draining rainwater as it is found to be heavy rainfall in most part of the Ethiopia during the rainy season [18]. However, gypsum-based ceiling tiles are more prone to moisture and fungi growth, as well as having low mechanical properties, especially when it comes to impact resistance [19]. These drawbacks motivate to work on ceiling boards using locally available materials. The objective of this study is to produce ceiling boards using low density pumice, steel mesh, cement and edible oil and study their mechanical and durability properties such as flexural strength, water absorption, change in weight, density, fire resistance, and screwing effect.

The other sections have been explored in the following ways. Literature review has been elaborated in section 2. Section 3 explored the materials and methods. Results and discussion have been investigated and discussed in section 4 and 5. Finally, with the summary points this paper was concluded.

2.Literature review

Polyvinyl acetate and false banana fibers were used as reinforcement along with the addition of the sawdust to produce FC panels [6]. The composite of false banana fibers and the sawdust ceiling board showed better performance. In another study [20] ceiling panels were prepared using natural sponge fibers as reinforced with 2% to 10%. From their work it was concluded the addition 4% fiber is found to be the best in overall strength and durability. FC boards of size 300 x 200 x 20 mm is prepared using wool fibers and gypsum with percentage variation and varying in fiber lengths of 10 - 35 mm [21]. They concluded that boards made from 30% wool fibers and 70% gypsum would satisfy minimum American Society for Testing and Materials (ASTM) requirements. Continuation of fibers studies on ceiling panels with other waste materials was studied [22] using, waste paper, sawdust, and polyvinyl alcohol binder materials with sisal fibers of boards size 400 × 250 × 5 mm. Water absorption of the boards is found to be increased with the increase in sisal fibers content as well the density of boards were reduced by 7%. Due the reduction in the density of boards they shall be used for non-structural applications in the construction industry. Use of wool and coil fiber as a green building material were in the FC panel by [5]. Use of these fibers were increased strength up to 90% and an increase in the resistance of water absorption.

Different chemicals were also used to study the different properties of FC panels. Magnesium hydroxide, ammonium polyphosphate, boric acid, and zinc borate were used as filler materials for FC boards [23] to evaluate their fire-retardant properties. It was reported that addition, magnesium hydroxide and ammonium polyphosphate as a fire-retardant material will enhance oxygen and increase fire resistance. Used methyl ketone peroxide with rise husk, saw dust, and reinforced polyester, for the production of FC boards of size 500 x 500 x 5 mm. [24]. The material used were passing through 1.18mm with different mixed ratio. They concluded 6:1 ratio was found to be economical and reduces company costs by 31.44 %. Methyl stearate and diatomite [25] shall also be used in the production of ceiling panels to increase the efficiency in cooling the rooms.

To study thermal conductivity, water absorption, and density, breadfruit seed coat and recycled low density polyethylene materials were used for developing ceiling boards [26]. The addition of these materials to the ceiling boards proved to be more effective compared to the existing ceiling boards. Recycled gypsum and wood waste, as well as polycarbonate plastics used to make compact discs (CDs) and digital video discs (DVDs), is used for the development of ceiling boards [13, 27]. The addition of wood waste had negative affects the flexural properties but still satisfy the minimum requirements, whereas polycarbonate plastic materials are found to improve properties.

Organic wastes such as palm kernel shell, rice husk and waste paper were also used to produce ceiling boards [28−30]. A study [29] composed of 30 x 40 cm FC boards prepared from palm kernel shell, balanite, and cement as binders, mixed with three different ratios of each mix material. Their investigation revealed mix proportion of palm, Balanite, and binder with 20/80 has the same physical and morphological appearance as asbestos ceiling boards with slightly higher density and durability. Rice husk and waste paper were used for the production of low-cost FC board [30]. The results with 50% of the combo showed positive responses in all parameters, suggesting the use of rice husk and waste paper together. To enhance the properties of gypsum board recycled rubber particles was used and it was noted there is a reduction in mechanical properties with the addition of rubber particles [31]. The combinations of polystyrene, sawdust and eggshell with different mix proportions were used to develop ceiling boards in Nigeria, and they are found to be more effective with the combinations of all the mix rather than using individual [9]. A study was conducted on FC [32] using different waste materials with the combination of rice husk, rice husk ash and waste paper, using the combinations had better lesser density compared to conventional once but the drawback is found to be in higher water absorption.

The previous studies suggested, fibers, organic materials, chemicals can be used for the production of ceiling panels.

In Ethiopia, ninety percent of the building roofs are sloped and are made up of truss work with steel and timber depending upon the budget of the client. The cost of ceiling can be reduced up to 50% compared to concrete slab [33]. In Ethiopia, ceiling boards are produced using locally available materials such as: POP, polyester and wood only. The other types of ceiling boards are imported from the different countries, by which the cost of construction is increased. In order to reduce the cost of construction, ceiling panels with low density aggregates and using of steel mesh shall be used for the production of FC boards as it is noticed that, till date it has not yet been explored in the production of ceiling boards. Hence, this article tries to fulfil the gap in the FC boards by producing the FC boards using local available materials with low weight. The study is limited to the mechanical and durability properties only. Microscopic properties are not studies due to the lack of facilities available.

3.Materials and methods

According to the literature review, the thickness of ceiling panels varies from 5-35 mm [21, 22, 24]. One of the objectives of this research work is to reduce the weight of the panels, hence low-density pumice aggregate was used to produce the panels. To optimize the thickness and mix ratio, number of trials were made with the different combinations of aggregate size to reduce the thickness of ceiling panels as well to have better bonding between the aggregate of binding material different mix ratio was considered for the trials. Stated that by using 12 mm pumice aggregate passing through a size of 4.25 mm has better bonding between aggregate and steel mesh [34].

Figure 1 shows the methodology adopted for the study. Initial trial mix of 1:2 (cement: aggregate) mix proportion with aggregate passing through 4.25 mm was used to produce the panels. Edible oil to create the voids in the panels for the reduction of weight. From the observation, it was noticed the ceiling panel weight was higher than expected due to the presence of large amounts of finesse content in the aggregate, this increase in the quantity is due to the crushing effect of coarse aggregates. Additionally, it is also observed the bonding between the steel mesh and mortar was satisfactory.

Due to increase in weight of the panels, the second trial was done with a different mix ratio with change in percentage of gradation of aggregates. The aggregate passing through the 4.25 mm and retained on the 0.3 mm aggregates was used to reduce the weight of panels with 1:6 mix proportion. In this trial it was observed, challenges in compaction of fresh mortar in the mould as well, there was a lack of bonding between the steel mesh and mortar after 24-hour observation. This lack of bonding is observed, due the omitting of the finer particles which are less than 0.3mm. In addition, it was observed the cement required to coat the aggregate was high because of the high percentage of larger particles.

From the two trials, it was observed, we can't omit finer particles completely and we the quantity of finer particles should not be more, which affects the weight of the panel as well, there will be a problem with bonding between the particles and thickness of panels less than 15mm will have problem in compacting the mix. The edible oil didn't have a significant effect on the creating of voids internally in the mortar. However, some surface voids were observed. This indicates the percentage of edible oil has to be increased to create a large number of voids. Hence, in the third trial, the thickness of the panels was increased from 12 mm to 30 mm with a mix ratio of 1:4. The aggregates were divided into two proportions70: 30 (aggregate retained on 0.3 mm: aggregate passing through 0.3 mm) and edible oil was used as an air-entraining agent with 2% dry weight of the total mass.

Figure 2 shows the different size of samples, total eighteen ceiling panels were casted of size 250×250×30 mm, and three samples of 500×100×30 mm for studying the flexural strength. Testing of specimens is done according to ASTM standards.

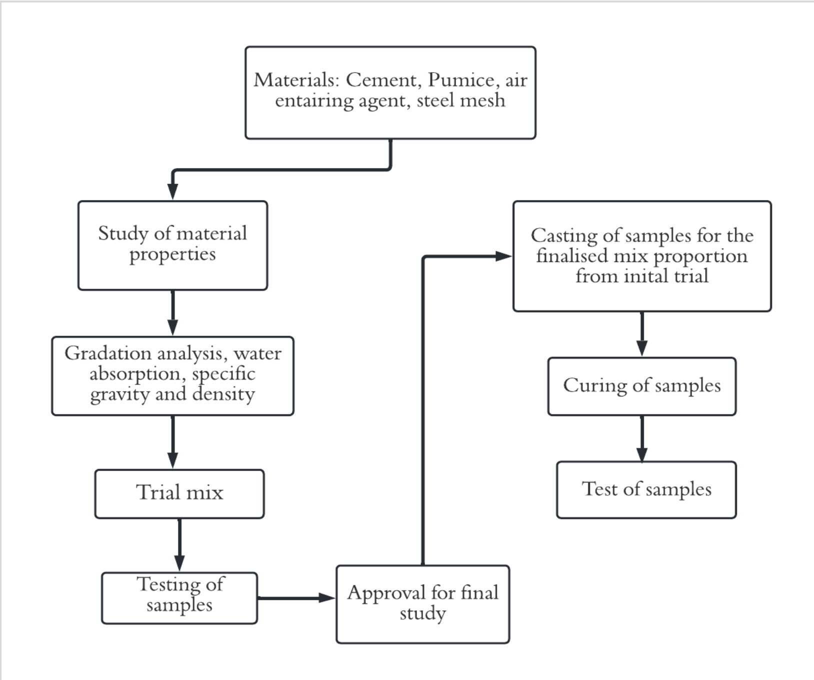

Figure 1 Work methodology

Figure 2 Beam and slab specimens

3.1Materials

For the casting of ceiling panels, locally available materials such as cement, pumice, edible oil are used.

Cement: Portland Pozzolana cement of 32.5 grade was used.

Aggregate: Is used from the locally available concrete block factory. The aggregate used is of low-density pumice, the aggregate is crushed into the required size and is presented in *Figure 3*. The gradation of aggregate results is shown in *Figure 4.* Properties of crushed aggregate are tabulated in *Table 1*.

Admixture: Edible sunflower oil is used as an air-entraining agent.

Steel square mesh: *Figure 5* shows the steel mesh used, which is locally available in the market. 1 mm diameter is used for the production of ceiling panels, one mm diameter steel mesh mechanical properties are taken from [35] and they are tabulated in *Table 2.* Since the panels are made of mortar, and it's weaker in the flexural strength, possibility of shrinkage cracks is high. Hence, steel mesh was used for the panels. Panels are reinforced with steel mesh by placing the steel mesh at the centre due to less thickness of the panels.

Table 1 Properties of fine aggregate (Pumice)

Specific gravity	1.34 g/cm^3
Cc	1.74
Cu	3.6
Percentage of water absorption	61.14
Density of aggregate	550 kg/m^3

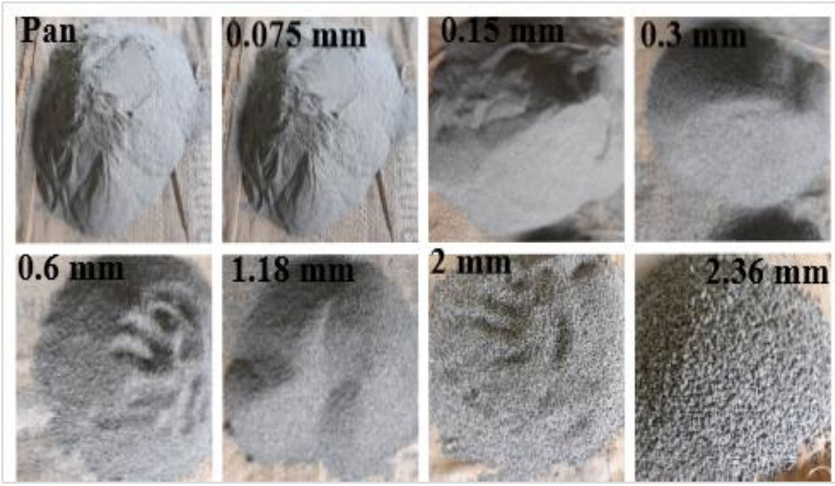

Figure 3 Fine aggregate

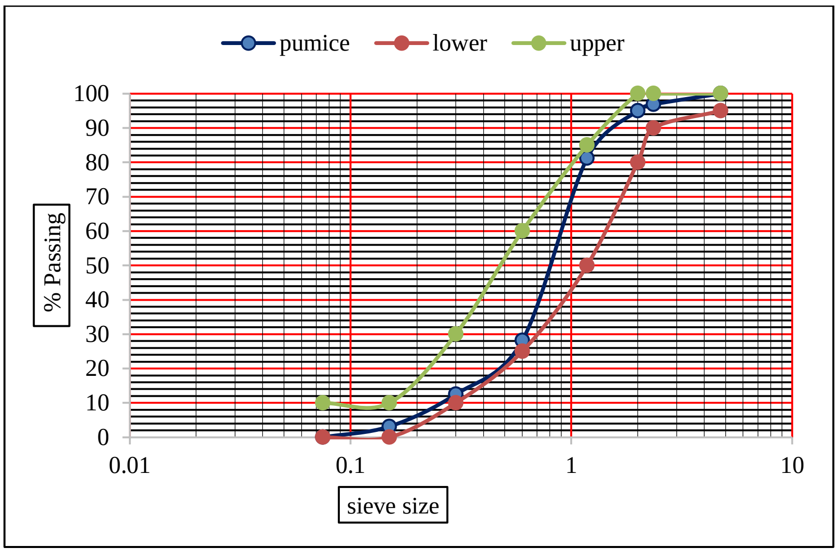

Figure 4 Gradation of fine aggregate

Figure 5 Steel mesh

For this research, the testing of samples is for flexural strength, water absorption, density, weight, fire resistance and screwing effect and neglecting the compressive strength due to the panels fail by flexure rather than compressive force.

Table 2 Properties of steel square mesh [35]

Diameter	1 mm
Tensile strength	405 MPa
Modulus of elasticity	95 GPa
Size of mesh	7×7 mm

3.2 Methods

3.2.1Flexural strength

The ceiling panels are subjected to bending effect, as they are placed horizontally as a slab. Hence, testing of the flexural strength of the panels was investigated with the specimen dimension 500 × 100 × 30 mm (L × b × d). Since the panel was 30 mm thick and which is difficult to do testing of the specimens with the support conditions. Hence, an adjustment was done using bricks at the support which is shown in *Figure 6*. Three-point load was applied to the specimens at a loading 1.3 mm per minute as per ASTM C293. The flexural stress is calculated using Equation 1. ceiling panels are tested at the age of 14 days for the increase in the production of panels.

$$\sigma_f = \frac{3FL}{2bd^2} \quad (1)$$

σ_f = flexural stress; F = applied load at failure; L= length of the specimen between the supports, b= width and d= depth of the specimen

Figure 6 Three-point loading

3.2.2Water absorption

Water absorption of the specimens is done to measure the volume of pores that can be reached by the aggregates for the volume of panels. During the curing process, three samples were taken to test the water absorption. In a ventilated oven, the panels were dried for 24 hours at 105°C to remove all of the water absorbed during the process. After they were removed from the oven, their weights were calculated and they were once again soaked in water for 24 hours. *Table 3* summarizes the weight measurements. The Water Absorption is calculated with Equation 2.

$$\text{Percentage of water absorption} = \frac{A-B}{B} \times 100 \quad (2)$$

Where A = wet weight of unit in kg,
B = dry weight of unit in kg.

3.2.3Density

Density test is conducted for three randomly selected ceiling panels. Initially all the panels were dried in an oven at 105°C for 24 hours, later they were brought to laboratory room temperature ±27^0 C, and dimension and weight of each panel are measured nearest to 10 gm. Density is calculated using Equation 3. The average of three samples is used as the density of ceiling panels and test results are tabulated in *Table 3.*

Density of panels

$$= \frac{\text{wet weight of the panels} - \text{dry wright of the panels}}{\text{wet weight of the panels}} \quad (3)$$

3.2.4 Weight

The dry weight of the panels was measured using 0.1gm accuracy in the digital balance and the results are tabulated in *Table 3.*

3.2.5Fire resistance

This test is conducted to measure the fire resistance of a ceiling panel as these panels are used in residential and commercial buildings. Due to the lack of laboratory facilities and to the practical condition, the ceiling panels were burnt openly for 1 hour as shown in *Figure 7*, later the panels were brought to the room temperature gradually.

Figure 7 Fire-resistance test of ceiling panels

3.2.6Screwing effect

The test was done to determine whether panels will resist the nailing effect during installation of panels and electric fixtures. *Figure 8* shows the test panels, the panels were driven with 12 mm electric screwdriver to make holes in the panels at a distance of 2 cm between each hole.

Figure 8 Screwing effect on ceiling panels

4.Results

The test results obtained from the flexural strength, water absorption, density, and weight test results of ceiling panels are presented in *Table 3.*

From the statical data analysis, it is observed P value is greater than 0.05 in all the cases, hence results obtained are insignificant.

5.Discussion of results

5.1Flexural strength

Table 3 shows the test results, the flexural strength of the specimens is zero. During the testing the panels, it was observed all the three specimens failed after 20-30 seconds of testing with zero readings on the machine display. This suggests that the panels don't flexural strength. Practically knowing the specimen shall have minimum flexural strength, which is not seen in this case. This could be due to the sensitivity of the machine required for testing the panels, as the panels are made of lesser in thickness and by low density aggregates. In addition, the samples are tested for 14 days to increase the production of panels by considering practical point of view which can be another factor for zero flexural strength. If the samples are tested for 28 days, we might see some gain in strength as it is observed in concrete.

Table 3 Test results of FC boards

FC Panels	Flexural strength	Water absorption %	Density (kg/m^3)	Weight (kg)
1	0	14.76	1053.19	1.95
2	0	16.16	1060.66	1.98
3	0	18.93	1070.69	2.075
DOF	2	2	2	2
Mean	0	16.61	1061.513	2.00
Variance	0	4.503	77.10	0.00425
P value	0	0.181	0.012	0.00424
F Value	0	0.22	0.0129	234.88

5.2Water absorption

Figure 9 shows the different percentages of water absorption in each ceiling panel. Each ceiling panel had different water absorption, which may be due to lack of compaction during casting. Since pumice is porous in nature, it will absorb substantial amounts of water due to the formation of tiny water pockets at a micro level, and these pockets release water to the surrounding medium, thus reducing the amount of water needed for curing. Many researchers have noted, this phenomenon in concrete [36, 37]. In this study, it is found that an average water absorption of 16.61% at the early age of curing, i.e., at 14 days, which is higher than the quality gypsum board reported [38]. As FC panels are placed inside as a second roof, water absorption property with on the slightly higher side will not impact much to the quality concern.

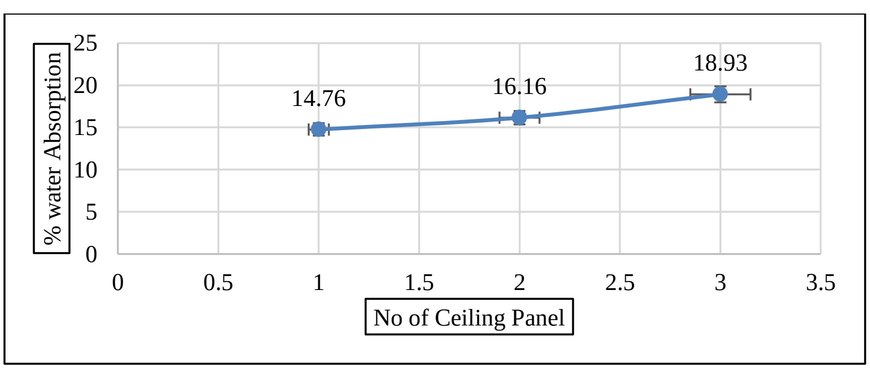

Figure 9 Percentage of water absorption Vs. number of FC panels

5.3Density of FC panels

In *Table 3* and *Figure 10*, it is observed the density ranges from 1053.19 - 1070.69 kg/m3. Though it was expected the density to be between 600-750 kg/m3, since low density aggregate and sunflower edible oil is used as air entering agent admixtures to produce voids in the panels for the reduction in density. From the physical observation, it was found that, these voids were not so close as it is observed in the aerated concrete [39]. This factor affected to increase the density of panels, then the expected once. The density of panels was compared with the density of lightweight concrete, which is in the range from 800 to 2000 kg/m3 as stated by British standards and European standards (BS EN) 206-1[40], for oven dried sample. Hence, it could be concluded that panels can be considered as lightweight. The standard deviation between the blocks was found to be 8.78.

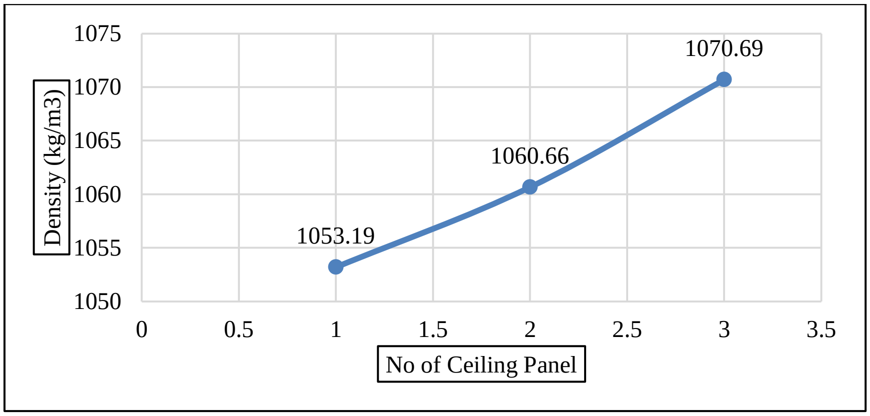

Figure 10 Density of ceiling panels Vs. number of FC panels

5.4Weight measurement

Ceiling panels weight is important as this load is transferred to the supporting members, e.g., the RCC slabs and trusses. Hence, in this research, it was attempted to reduce the weight of the ceiling panels which is one of the objectives. In *Figure 11*, the ceiling panel weight ranged from 1.95 to 2 kg for a panel size of 0.25 x 0.25 m, or roughly 32 kg/sqm for a 30mm thick panel, which is slightly higher than the gypsum board weight of 20 kg/sqm for a 25.4mm thick panel [41]. In order to reduce the weight of the FC panels, the panels shall be prepared using aerated concrete concept, which will help in reduction in weight.

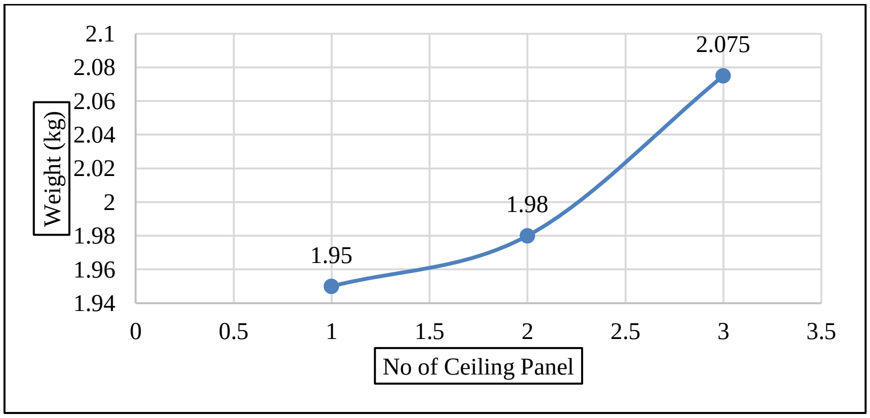

Figure 11 Weight of ceiling panels Vs. Number of FC Panels

5.5Fire resistance

The samples were black in color on their surface due to deposition of carbon, which did not last as the color faded when the panels were cleaned with dry cloth. A wire brush was scraped for 3 minutes on the surface of the panels to determine whether there is loss of material and loss of bond between the mortar and is there any change in the cross-sectional dimension. From the observation, it is observed, there is a loss in the material or a change in dimensions of the panels.

5.6 Screwing effect

From the test results, the panels showed no sign of cracks visible to the naked eyes and the screws were held firmly in the FC panels as observed in *Figure 8*. Similarly, the screwing test was conducted on Gypsum boards which were made with wool sheep fibers and similar results were observed [21].

Previous test results

From *Table 4*, the present study results are compared with the previous studies to know how effective the pumice and steel wire mesh FC boards are effective. The flexural strength of the previous studies was done using cylindrical specimens, whereas in the present study it was done with the thickness of the actual panel. The previous study was conducted at 14 days strength; hence, flexural strength was negligible compared to wool and natural materials used. The screwing effect was effective same as previous studies.

A limitation of the study is that flexural strength was measured for 14 days and a microscopic study was not performed due to lack of laboratory facilities.

A complete list of abbreviations is shown in *Appendix I.*

Table 4 Comparison of mechanical and durability properties with previous literatures

Reference number	Material used	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)	Water absorption (%)	Density kg/m^3	Weight kg/m^2	Fire resistance	Screwing effect
Present study	Pumice	-	Nil	16.61	1070.69	32	Effective	Effective
2	Wood waste	2.17	1.23		702	-	-	-
4	Polyvinyl acetate and false banana fibres	7.03	5.13	25.13	973	-	-	-
6	Natural sponge fibre and pulverised waste paper	1.342	0.690	65.783	-	-	-	-
7	Wool fiber and gypsum	6.6	5.4	3	-	-	-	Effective
9	Wool, coir fiber and gypsum		0.6	12	1220	-	-	-
11	Rice husk and saw dust	8.8	5.8	-	-	-	-	-

6.Conclusions and future work

In this research, whether crushed pumice, steel mesh, and edible oil (air-filled agent) can be used to produce FC and whether the ceiling panels will meet the mechanical requirements of the standards were attempted addressed. The flexural strength of the panels is negligible with inclusion of steel square mesh and didn't have any impact on the 14 days flexural strength. The average density of the ceiling panels is 1058.18 kg/m3 which is lighter in density and falls under low density concrete. The average percentage of water absorption 16.61%, which is higher than the ASTM C1761. There was no damage of ceiling panel at the edges and there is no loss of bondage between the mortar for the uncontrolled temperature fire for 1 hour which indicates the panels are good at fire resistance. The average weight of the panels 32 kg/sqm, which is found to be slightly higher than gypsum boards. But the properties of fire resistance and screwing effect showed positive. From the above, it could be concluded that, the FC panels shall be used for residential and commercial purpose. Further studies shall be made with 28 and 56 days to know the behavior of flexural strength and water absorption properties.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Kumar Shantveerayya: Conceptualization, investigation, analysis and interpretation of results, writing – original draft. **Mahesh Kumar C L:** Methodology, analysis and interpretation of results, resources, writing – review and editing. **Shwetha K G**: Methodology, software, data collection, writing – review and editing. **Yodit Fekadu:**

Resources, writing – review and editing. **Firazzar Berhanu Mendere:** Visualization, writing – review and editing. **Sowjanya G V:** Supervision, writing – review and editing.

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Appendix I

S.No.	Abbreviations	Description
1	AC	Air Conditioning
2	ASTM	American Society for Testing and Materials
3	BS	British Specifications
4	BS EN	British Standards and European Standards
5	CDs	Compact Discs
6	DC	Drop Ceiling
7	DVDs	Digital Video Discs
8	EN	European Standard
9	FC	False Ceiling
10	gm	Grams
11	GPa	Giga Pascal
12	Mpa	Mega Pascal
13	POP	Plaster of Paris
14	PVC	Polyvinyl Chloride
15	RCC	Reinforced Cement Concrete