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Research paper

Behaviour of Gypsum Plasterboards Under Mechanical Loads and Thermal Effects

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Abstract

This paper presents an experimental study conducted to investigate the behaviour of gypsum plasterboard assemblies subjected to mechanical loads and thermal effects. These assemblies were boxes in shape and connected to reinforced concrete slabs. Each side of gypsum plasterboard was fastened using either two or three bolts. The loads were applied at the assembly centre and the maximum flexural load at failure was recorded. Besides, the elapsed time to failure was monitored.The results obtained showed that the material property of the plasterboard and the method of fastening are governed the global behaviour of the tested samples. The average flexural braking loads at failure were 538 N and 564 N for the assemblies fastened with two and three bolts, respectively. The corresponding failure times under conditions of fire exposure and mechanical loading were 2.1 minutes and 1.7 minutes, respectively. Suitable emended were made for the expressions suggested by the related codes of practice in order to suit the experimental results

Keywords: *Gypsum plasterboards; flexural load; thermal effects*

1. Introduction

Many of construction processes nowadays involve applications of gypsum plasterboards in different parts of the structure. This is basically due to the easy of work with these plasterboards, availability of the gypsum and the reasonable cost of this application. Several research works [1-4] illustrated examples of utilizations of gypsum plasterboards in roof decoration, partition walls, loadbearing walls, thermal insulation purposes and fire protection. Besides, it was considered as an environmentally friendly material [5 and 6].

Some of previous literature stated that the early scientific research work running out to investigate the protective properties of the bulk gypsum material may be back to the last century [1]. Exploring the governing parameters of the experimental measurements for this research work was carried out by West and Sutton [7] and Khalil et al.[8]. In case of fire exposure, gypsum material showed a notable shrinkage, thereby its stability will be affected. On this basis, different kinds of gypsum compositions were designed with suitable fillers such as Vermiculite in order to mitigate this shrinkage. However, some of these fillers have adverse effect on the mechanical performance of the gypsum product [9]. Other technique was concerned with the properties of the used surface sheets of the plasterboards and promotion performance was obtained [10]. The deterioration of gypsum material due to the fire effect can be explained by the dehydration reaction. In this reaction, the gypsum is firstly converted to hemi-hydrate gypsum and then dehydration process is completed. Consequently, the material loses its capability to provide thermal protection [11].

For the assembly of gypsum plasterboard, numerous experimental investigations have been conducted to explore the behaviour of different configurations at fire events. Few of these investigations dealt with the fire performance of horizontal assemblies which exhibit more severe deteriorations than those of vertical assemblies. This can be attributed to the combined effect of the self-weight resulting from the action of gravity and thermal loading [12].

Due to the declare in the code of practice regarding to the spacing of fastened bolts, this study deals with the effect of two assembly configurations of gypsum plasterboards with concrete roofs. This was associated with the effect of the mechanical loading at both ambient and high temperatures. On this basis, an experimental investigation setup was design in order to address the parameters governing the global behavior of such configurations.

2. Experimental Programme

The experimental programme of this research focuses on exploring the behaviour of roof assemblies using regular common gypsum plasterboard under effects of thermal and/or mechanical load. For this purpose, specimens of small scale reinforced roofs (slabs) were first casted. After these specimens being hardened, frames of gypsum plasterboards were then applied in two different configurations (as explained below). The experimental tests comprised those of flexural braking load, thermal resistance and failure modes.

2.1. Materials used

Normal weight reinforced concrete with a characteristic compressive strength of 25 MPa was selected to producing the small scale slabs. The constituents of the former concrete were cement type I, sand and gravel. Ordinary Portland cement (42.5) produced by Lafarge Company which compliant with the BS EN 197-1 [13] was used. Natural sand for general purposes was used as a fine aggregate. Both chemical and physical properties of the used sand were satisfied the requirements of the BS EN 882:1992 [14].

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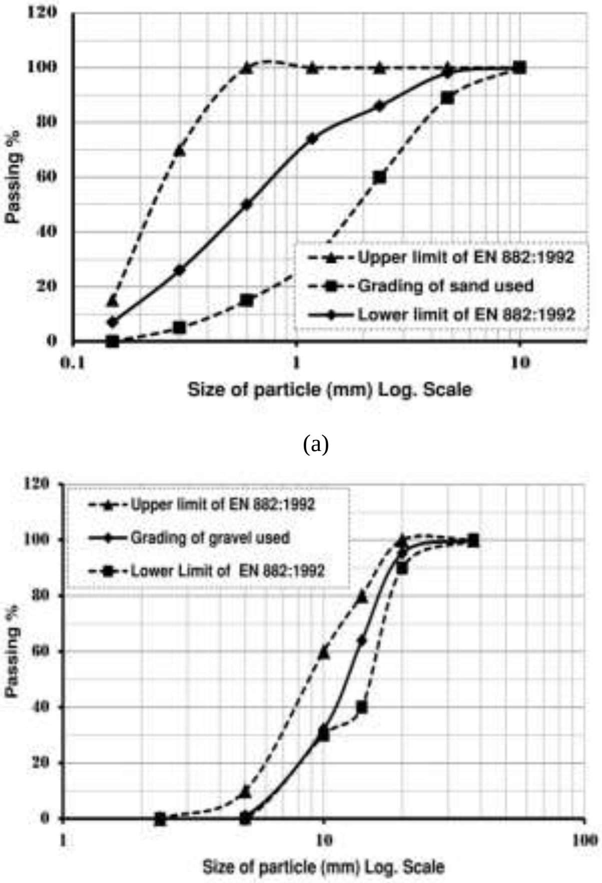
Crushed gravel was used as a coarse aggregate with a maximum particle size of 10mm. The grading curves of both sand and gravel particles in addition to the upper and lower limits of EN 882:1992 [14] are presented in Figure 1. In order to reinforce the specimens of concrete slabs, BRC steel bars with nominal diameter of 6 mm were used in two layers. Each layer has 100 mm c/c spacing in both directions. It was compliant with requirements of the ASTM A615/A615M-01b: Grad 40 [15]. Table 1 shows specifications of the BRC rebar used in this study.



(a)

(b)

Figure 1: Grading of aggregate used (a) sand and (b) gravel

Table 1: Properties of BRC steel bars

Property	Results	Limitation of ASTM A615/A615M-01b: Grad 40
Tensile strength (MPa)	778	420
Yield strength (Mpa)	380	280
Elongation for length of 200 mm	30	----

The processes of preparation the specimens' moulds and the casting of concrete slabs were carried out according to the BS EN12390-1, 2 [16,17]. The operations of curing were performed after 24 h of the samples casting and demoulding. It was done by immersing all of the concrete slabs in a basin of water at a temperature of 20 ± 2 ˚C.

In order to apply the gypsum pasteboard, a steel frame was implanted upon the upper surface of concrete specimens using steel angle with equal side length of 30mm and thickness of 3mm. It was comply with the requirements of the BS EN 10025-1/2 [18] and has tensile strength, yield point and elongation of 400 MPa, 255 MPa and 25%, respectively. Drilled bolts (screw with Phillips flat head), were used to fasten the steel angle into the concrete surface. The gauge of the screw was 1/4"-28. A regular common gypsum plasterboard type A produced by Mada Gypsum Company was used in this study. This board lie within the classification of the BS EN 520:2004 [19]. It has a thickness of 12.5mm with length and width dimensions of 2.8m and 1.2m, respectively. The density and flexural strength of the former boards were 784 Kg/m^3 and 784 N, respectively.

2.2. Design of the slab and gypsum plasterboards assemblies

The geometry of the reinforced concrete slabs was considered in order to suite the objective of this research. In this regards, eight square small scale slabs were designed with a side length of 50 cm and 10 cm thick. The gypsum plasterboards were formulated as a closed box with dimensions of 30cm×30cm and a depth of 10cm. The base of the plasterboard box was fastened using raw plug or so-called anchor technique with plastic holder. Two assemblies were designed, namely by using two and three fastening bolts in each side of the box base, as shown in Figure 2. The top side of the box was closed by screws with similar numbers to those used at the base of the box. This in turn means using 12.5 mm or 8 mm spacing between the fastened screws in each side.

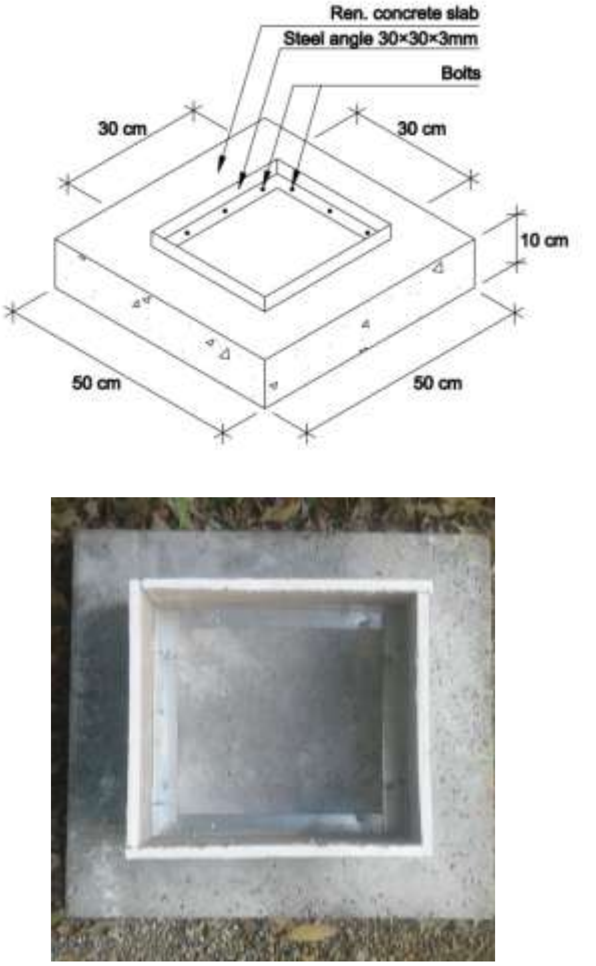


Figure 2. The layout of the concrete- gypsum plasterboard assemblies

2.3. Test set-up

The test was carried out using a highly rigid steel frame with dimensions of the upper base suitable to those of concrete slab samples. All of the tested assemblies were incorporated steel hock at the box centre, so that the mechanical loads can be gradually hanged up, as shown in Figure 3. The assemblies were placed within the test rig and their positions were centered so that the concrete edges are clearly reposted by the rig body. This in turn means providing a simply supported reaction for the slabs and keeping the box of the gypsum plasterboard with their loads freely dangling. The experimental test was carried out utilizing two methodologies. The first methodology was designed to measure the flexural braking load of the assemblies subjected to mechanical loading at ambient temperatures. Whereas, the other methodology was set-up to measure the time elapsed at which the failure of the plasterboards occurre under combined effect of high temperatures and half of the ultimate flexural braking load of the samples. The thermal loads were applied using flame apparatus which gives range of temperatures of 950 °C.

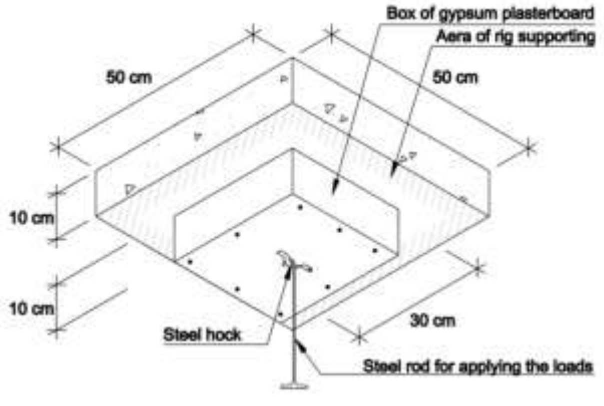


Figure 3: Test set up of the concrete- gypsum plasterboard assemblies

3. Results and discussions

3.1. Flexural braking load

Figure 4 shows the results obtained for the mechanical testing in term of flexural braking load of the gypsum plasterboard assemblies at ambient temperatures. It can be seen that the more number of fastened bolts used imply more flexural braking load for the assembly. This was expected, as the applied load is distributed overall the fastened bolts. The increase in the value of flexural braking load due to the use of three fastening bolts compare to those of two bolts was 26 N. This was not equivalent to the contribution of single bolt which reached 67.5 N for the case of using two fastened bolts in each side. There are two possible explanation for this observation. These are the material failure of the plasterboard which is not governed by the strength of the bolts itself; and the nature of the applied load which usually involves small eccentricities resulting from the imperfection effect. The value of such imperfection is recommended to be no more than (hef / 450) as per in the BS EN 1996-1-1 [20]. Both of these factors combine and localized stresses might be occurred at a specified action zone.

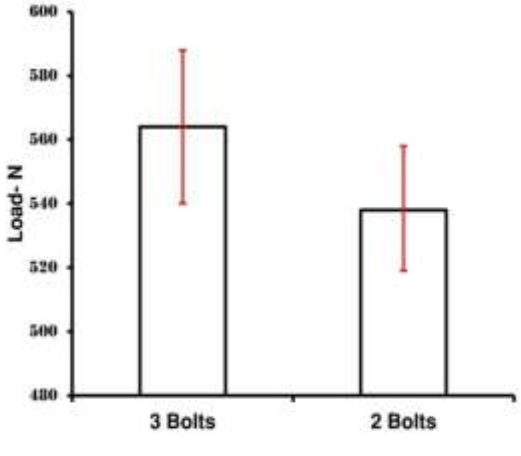


Figure 4: Flexural braking load of the gypsum plasterboard assemblies at ambient temperatures

The BS EN 520:2004 [19] suggested that the flexural braking load for different kinds of gypsum plasterboard can be calculated in both longitudinal and transverse directions from Eq. 1 and 2, respectively:

$$F = 43t \qquad \text{Eq-1}$$

$$F = 16.8t \qquad \text{Eq-2}$$

Where F is the value of flexural braking load and t is the thickness of gypsum plasterboard.

Comparing with the results obtained from this study for the assembly of two fastening bolts, Eq-1 is a reliable predicting formula to the value of flexural braking load in the longitudinal direction. However, the constant of the aforementioned equation (i.e. 43) should be amended to 45 in order to suit the results obtained for the assembly of three fastening bolts.

It is also important to mention that the BS EN 520:2004 [19] referred to when the substructure includes supporting members in two directions, the maximum span in either direction shall not exceed a dimension equal to 100 times the thickness of the gypsum plasterboards. The latter seems to be unacceptable.

Figure 5 presents the failure modes of both gypsum plasterboard assemblies at ambient temperatures. In general, identical failure modes for both assemblies were observed. The propagation of the failure path was noted at the centre of the box and the nearby zone then might be extended to the box edges. This was predictable, as the maximum bending moment located at the mid span of the assembly, so it is considered as the critical zone for cracking and failure. This can be attributed to the nature of the supporting edges of the test rig which reflects the phenomenon of simply supported reactions. However, no failure sign was observed at the interior bolts which has been used to fastening the steel angles to the concrete slabs. This could be related to the high stiffness of such steel angle resulting in a more tightened to the plasterboards. On the other hand, a notable deflection was noted near the fastening bolts of the external box face.

(a) Assemblies fastened with 2 bolts

(b) Assemblies fastened with 3 bolts

Figure 5: Failure modes of the gypsum plasterboard assemblies at ambient temperatures

3.2. Thermal resistance

The thermal resistances of tested assemblies in terms of the failure time under the effect of high temperatures combined with 50% of the maximum flexural braking loads are presented in Figure 6. All of the tested assemblies exhibited a failure time less than 2.5 minutes. Nevertheless, samples with two bolts fastening showed longer time for thermal resistance than those of three bolts. This manner confirms the justification provided for the behaviour of the assemblies under the effect of the mechanical loads (i.e. Section 3.1). The difference in failure time between the tested assemblies was about 20%. Such issue may also be related to the difficulties associated with the controlling of the test due to the variations of the applied temperatures and the spacing distance between the samples and the fire source.

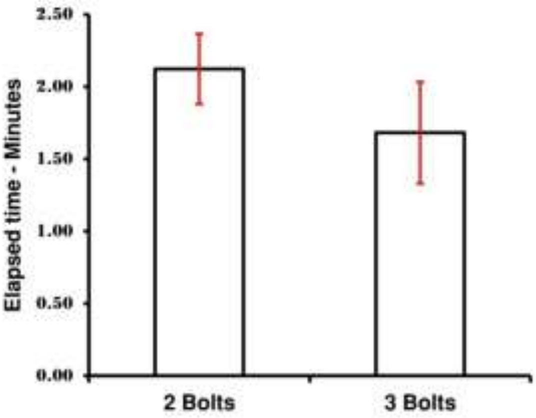


Figure 6: Elapsed time to fall of the gypsum plasterboard assemblies under combined effect of high temperatures and mechanical loads

At any case, it was recognized that the outer (cladding) layer is responsible for the resistance of pull-out failure [21]. If other conjunction layers are available, their contributions will be less than that of the outer one. This was explained by the deterioration of these layers resulting from the direct contact effect of the fire after the breakdown of the first layer . The failure of the gypsum plasterboards at high temperatures is generally identified as the charring so that at least 1 % of the board area gotten fallen off. On this basis, the BS EN 1995-1-2 [22] suggested the expression in Eq. 3 to calculate the time of the start of charring (t_{ch}) at locations adjacent to joints with a width of more than 2 mm. Whereas, Eq. 4 was driven to estimate the failure time(t_f) of panels with respect to pull-out failure of fasteners [22].

$$t_{ch} = 2.8h_p - 23 \qquad \text{Eq.3}$$

$$t_f = t_{ch} - \frac{l_f - l_{a,min} - h_p}{K_s K_2 K_n K_j \beta_0} \qquad \text{Eq.4}$$

Where

h_p is the thickness of cladding, one layer; l_f is the length of fastener; $l_{a,min}$ is the minimal anchorage length of fastener; K_s is the cross-section factor; K_2 is a protection factor; K_n is a factor to convert the irregular residual cross-section into a notional; K_j is the joint coefficient and β_0 is the one-dimensional design charring rate.

Regarding to the gypsum plasterboard type A, the former code of practice [22] pointed out that the failure time (t_f) should be taken as:

$$t_f = t_{ch} \qquad \text{Eq.5}$$

All of the above equations (Eq.3 and Eq.4) concerned with the resistance time of gypsum plasterboard assembly at a pure fire event and no allowance was made for the mechanical action. Applying Eq.3 gives a failure time (t_f) of 12 minutes which is overestimated when compared with the results obtained in this study (i.e 2 minutes). In this regards, modification is needed in order to predict the time of failure resistance under combined effects of mechanical loading and thermal action. This may be obtained by subtracting the elapsed failure time due to the mechanical loading from the value of Eq.3.

Other point to be mentioned here, it was stated that the perimeter and internal spacing for screws should not be greater than 200 mm and 300 mm, respectively. These limitations seem to be more reliable than that stated for the case of pure mechanical loading (Section 3.1).

(a) Assemblies fastened with 2 bolts

(b) Assemblies fastened with 3 bolts

Figure 7: Failure modes of the gypsum plasterboard assemblies at ambient temperatures

Figure 7 shows the failure modes of both of the gypsum plasterboard assemblies under combined effect of mechanical load and thermal action. Similar failure modes were observed, and the global affected area was in the middle zone of the samples. This failure manner was due to the charring of the outer cladding layer, which led to speed up the failure occurrence within few minutes. Visible cracks were noted at one of the box edges connected to the central spall out. No failure was observed near the fastening bolts. This is indicative for enough spacing between the bolts that provides supporting to the entire system. Color changes were also noted from white, gray to black.

4. Conclusions

This study was conducted to exploring the behaviour of gypsum plasterboard assemblies under combined effect of mechanical loading and thermal exposure throughout an experimental investigation. A comparison was also made with the related code of practice. The main significant findings of this study can be summarised as follows:

1. The type of framing have no significant effect on the mechanical strength and fall-off time of the gypsum plasterboards.
2. The flexural braking load slightly increases with decreasing the distance of fasteners of the panel edges.

3. The critical failure zone was at the freely supported area (middle zone of the panel).
4. The BS formulas which is developed to calculate the flexural braking load and failure time at combined action need for emending.
5. The characteristics of the outer cladding layer are dominates the overall behaviour of the gypsum plasterboards when exposed to high temperatures.

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