THE INFLUENCE OF ASPECT RATIO OF REINFORCING FIBERS ON MECHANICAL PROPERTIES OF GYPSUM MATRIX COMPOSITE PANELS

H. Elahi [1], A.S. Motevasseli [2], and J. Aghazadeh [3]

[1] Ph.D. Student, Faculty of Mining and Metallurgical Engineering, Amir Kabir University of Technology, Tehran, Iran
[2] M.Sc. Student, Department of the Research and Development of Composites, Malek-e-Ashtar University of Technology, Lavizan, Tehran, Iran
slim_shahrokh@yahoo.com
[3] Faculty of Mining and Metallurgical Engineering, Amir Kabir University of Technology, Tehran, Iran

ABSTRACT

One of the most important parameters affecting the properties of composites is the shape of the reinforcement, as well as its distribution throughout the matrix. It has been proven that composites reinforced with continuous fibers, in spite of the high price of the production of fibers, exhibit better properties than the ones reinforced with discontinuous reinforcements. The shape of the reinforcements is determined by their aspect ratio, which is defined as the ratio between the length and the diameter of the reinforcements. Fibers have the highest aspect ratio among different types of reinforcements. Common problems in using gypsum panels include their low strength, low toughness, low impact resistance. In the current research, gypsum panels have been reinforced with Kevlar fibers of different aspect ratios to overcome the mentioned problems. Moreover, the effect of the size of Kevlar reinforcing fibers on the mechanical properties of gypsum matrix composite panels has been investigated.

1. INTRODUCTION

Composites have become an important group of engineering materials, as they offer better physical and mechanical properties in comparison to unreinforced materials. Different types of materials can be used as the matrix of composites, including metals, polymers and ceramics. An important aspect of researches on composites has been the investigation of their mechanical properties [1].

Despite their excellent high-temperature properties, the intrinsic brittleness of ceramics limits their usage in applications where high strength is needed. In the past few decades, thin fibers of different dimensions with a homogenous and irregular distribution in the matrix have been used to decrease the brittleness of ceramic materials and to produce isotropic conditions.

Different types of materials produced in different shapes and sizes, such as plastic fibers, are used to reinforce ceramic materials. Cork, wood filings, linen and fiberglass are among materials that are reported to reinforce gypsum [2,3,4]. One of the most important parameters of fibers is their apparent ratio, which is defined as the ratio of the fiber length to the fiber diameter. In general, as this ratio increases, the composite strength increases, until it reaches a maximum.

Fibers have the highest aspect ratio among different types of reinforcements. High-performance composite applications require reinforcement by fibrous materials with outstanding mechanical properties. Especially, polymeric fibers, such as Kevlar fibers are well suited to high-performance composite applications, because they combine a high specific strength and modulus with a high thermal resistance and chemical inertness. Furthermore, they exhibit low electrical conductivity compared with metallic or carbon fibers [5].

In the present study, Kevlar fibers have been utilized to reinforce gypsum panels. The effect of the size and distribution of the fibers on the mechanical properties of the gypsum matrix composites have been investigated.

2. EXPERIMENTS

Three types of sample panels with dimensions of $66.6 \times 50 \times 7\,\text{cm}$ were prepared. In all three groups, building gypsum was used as the matrix material.

2.1 Composite with chopped fibers

Chopped Kevlar fibers of 12mm length were used to reinforce the first group of samples. 2.5 vol.% of the fibers were added to the gypsum before the addition of water. Gypsum and the fibers were mixed to result in a homogenous and irregular distribution of fibers in the matrix.

2.2 Laminated composite panels

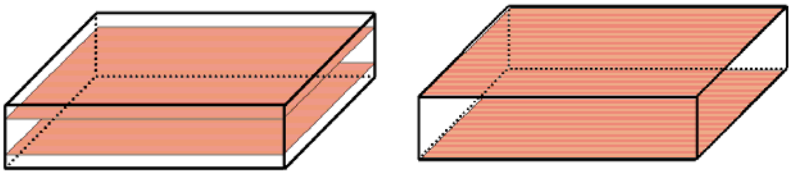
Long parallel Kevlar fibers (see Figure 1) were placed 1cm below and above the top and bottom surfaces of the panel mold. The mixture of water and gypsum were then added to form the gypsum matrix composite.

Figure 1: Long parallel Kevlar fibers used in laminated panels.

2.3 Improved laminated composite panels

To fabricate improved laminated composites, unreinforced gypsum panels were fabricated. Long fibers were then placed on the surfaces of the panel. Afterwards, some fresh and non-stiffened mixture of water and gypsum was applied over the fibers to cover them and form the composite panel.

Figure 2 indicates a schematic picture of the two types of laminated composites.



(a) (b)

Figure 2: Schematic representation of (a) laminated gypsum matrix composite panel and (b) improved laminated gypsum matrix composite panel.

After preparing the samples, triple point bending test was applied for the determination of their bending failure load. Based on the standard of the triple point bending test, three panels of each type were needed. Before the test, panels were heated in an oven under the temperature of 40 ± 2 to become absolutely dry, and to ensure their weight would be constant and would not change due to water evaporation.

3. EXPERIMENTAL RESULTS

The load-displacement diagram resulted from the triple point bending test for the composite reinforced with chopped Kevlar fibers, is shown in Figure 3.

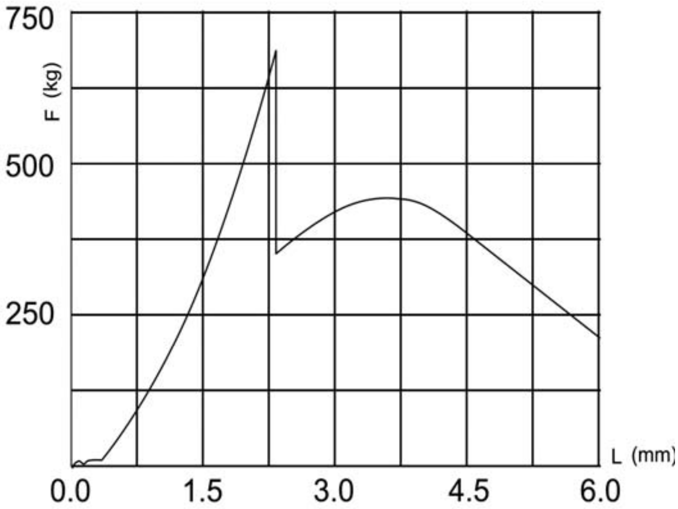


Figure 3: Load-displacement diagram for gypsum composite panel with chopped Kevlar fibers.

Figure 4 shows the load-displacement diagram of laminated composite panels.

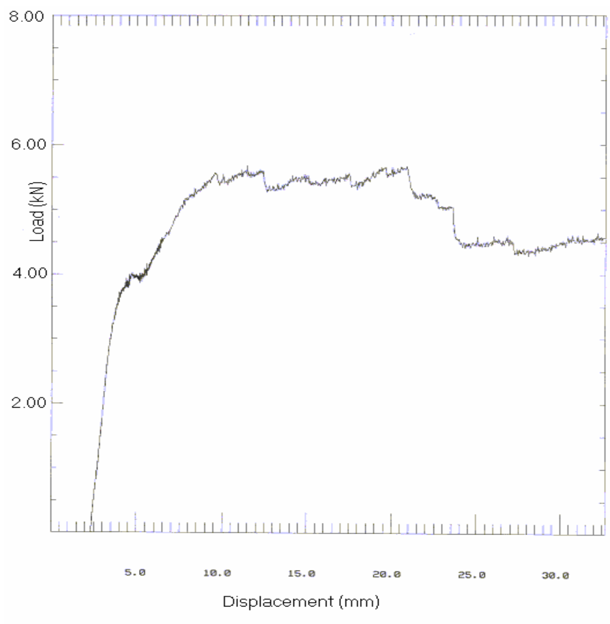


Figure 4: Load-displacement diagram of laminated composite panel.

The result of the triple point bending test for the improved laminated composite panel is shown in Figure 5. Also, the mechanical properties of the three types of composites, resulted from the bending test, have been shown in Table 1.

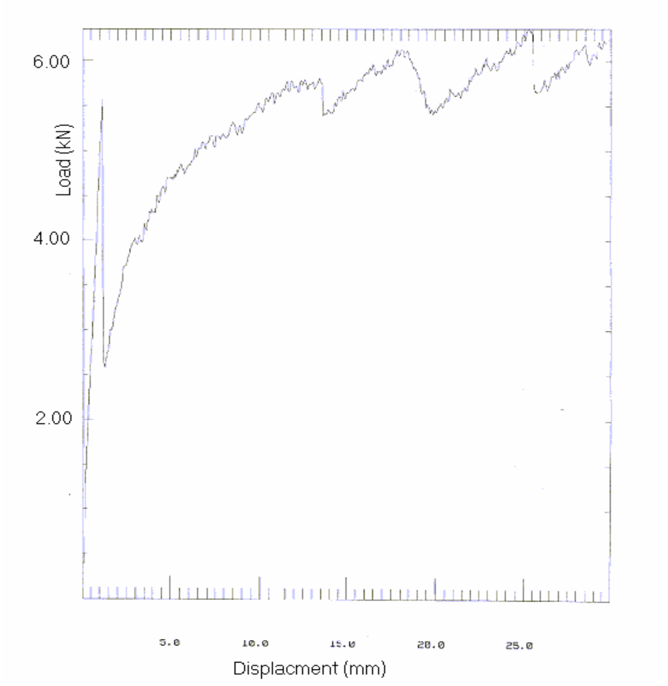


Figure 5: Load-displacement diagram for improved laminated composite panel.

Table 1: Mechanical properties of gypsum matrix composites reinforced with Kevlar fibers of different dimensions.

Type of Panel	Maximum Load (kg)	Tolerated Load After Matrix Failure (kg)	Total Absorbed Energy (J)	Fiber Consumption (g)
Composite Panel With Chopped Kevlar Fibers	690.0	350	19.95	840
Laminated Composite Panel	577.5	Not Determined	125.00	140
Improved Laminated Composite Panel	650.0	260	138.00	180

4. DISCUSSION

In the gypsum composite panel reinforced with chopped Kevlar fibers, as can be seen in the corresponding diagram, the amount of load drops after the initial fracture, but increases again, as loading continues, until it reaches a maximum. After that, it begins to approach zero with a specific slope, where final fracture occurs and the panel breaks into two pieces.

Although the matrix material is brittle, a noticeable part of the applied stress is transferred to fibers; hence the ultimate strength rises. In this case, the site of crack initiation is either the matrix or the matrix-fiber boundary.

After the maximum point, the matrix fails and crack grows inside it. In such a situation, what hold the two separate pieces of the panels together are the polymer fibers which act as a bridge between the two pieces (see Figure 6). The mechanical bond between the polymer and gypsum prevents full separation of the two panel pieces.

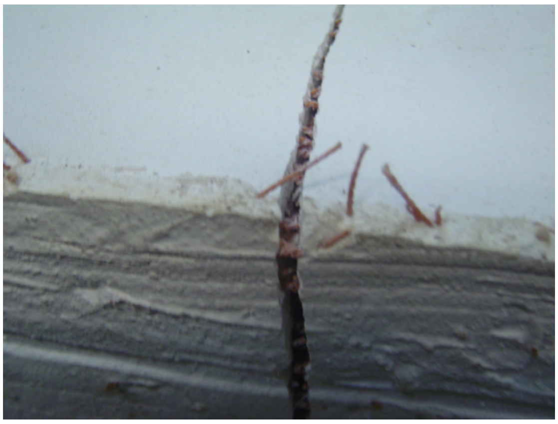


Figure 6: Picture of the cracked matrix: polymer fibers act as bridges between the two pieces.

The considerable area under the load-displacement diagram indicates the high toughness of the composite. The mechanism which leads to this increase in toughness is similar to *bridging phenomenon*. The difference is that, instead of fracturing of the fibers due to the applied force, the fibers are *pulled out* of the matrix. This consumes energy and results in high toughness.

As can be seen in Figure 3, the strength of the panel increases after its sudden drop. This observation is a result of fracture resistance of gypsum crystals adjacent to the fibers. As crack grows, the fibers are pulled out of the matrix, resulting in consumption of energy. Gypsum crystals adjacent to fibers prevent the displacement of the fibers. Therefore, these crystals contract and apply some force to other gypsum crystals. As a result of this interaction and contraction, the force needed to pull out the fibers increases and the increase in the diagram is seen. As displacement and crack length increase, the number of fibers which prevent full separation of the two pieces of the panels decrease; the panel can bear less load and finally full failure occurs.

As can be seen in Figure 4, the behavior of the laminated composite panel is totally different from the behavior of the composite panel reinforced with chopped fibers. Maximum tolerated load in this type is less than that of the previous panel and is about 578 kg, but the absorbed energy, which is proportional to the area under the diagram, is much higher.

The first stage of failure, which is relatively fast and noisy, is a local cracking due to the presence of maximum surface tensile stresses in the outer thin surface of the panel. When the load reaches the ultimate strength of the outer layer, such cracking occurs. The created crack is a shallow one, which lies across the panel and ends into the layer of fibers. Crack growth is stopped as it comes to the fiber layer, but as the load increases, the direction of crack growth changes and it begins to grow through the panel. This causes the lower surface of the gypsum layer to separate from the fibers, but still the tolerated load by the panel increases and the diagram will rise. When the crack reaches the fiber layer, it cannot pass this strong and elastic layer, and as the bond between gypsum and fibers is not that strong, the crack begins to separate the fibers from the gypsum below. Therefore the gypsum matrix below does not bear any load and is gradually separated from the fibers. The maximum load is tolerated by fibers which are under maximum tensile stress. As these fibers are not stiff, they begin to bend. The gypsum matrix can bear such deformation to a specified limit and after that it fails suddenly with a crack ending in the fiber layers at both sides. Figure 7 shows such a crack.

Figure 7: The crack occurred after the middle layer fails in laminated composite panel.

The bearable load begins to reduce now. The middle layer does not bear any load no more and almost all the applied load is tolerated by the lower fiber layer. Fibers of this layer continue to bear the load until no adhesion force between them and gypsum remains. They are pulled out one by one after that. In this situation, the friction force between the fibers and gypsum bears the applied load. The load is reduced, while rising and falling periodically, and the crack grows between the upper gypsum layer and fiber layer, along the panel.

The noticeable point about these panels is that, after the complete failure, the gypsum layers of the panel are not absolutely destroyed and still bear a high load. They also show a high flexibility; they can be bent more than 11 cm at the center. If the applied load is removed in first stages of loading, the panel shows an elastic behavior and regains its initial dimensions.

The role of the fibers in this panel is to some extent different from the previous one. In panels with chopped fibers, the fibers tolerate the load transmitted to them from the matrix, and also stop crack growth and full separation of the two pieces of panel. In the laminated composite, however, bridging does not occur. The load is transmitted to the fibers through fiber – matrix interface and as fibers are stronger, almost all the applied load is tolerated by them. This can also be seen in Figure 4, where the load drops slightly after the primary failure, whereas in the previous panel the load dropped sharply. The elastic behavior of the panel also shows that elastic fibers cause the panel to go back to its initial conditions. In these panels too much energy is spent to pull out the long fibers and thus toughness increases.

As can be seen in the load-displacement diagram of the improved laminated composite panel, there is a linear load increase in this diagram which reaches its maximum at 565 kg. Afterwards, the matrix fails and the diagram begins to descend. In this portion of the diagram, both matrix and fibers bear the applied load. Tolerated load by the matrix can be calculated by subtracting the tolerated load after primary failure from maximum load, which yields 300 kilograms. The maximum load tolerated by long Kevlar fibers is 260 kg, which can be observed in the load – displacement diagram immediately after the matrix failure, because the fibers alone bear the applied load after the failure. After the matrix fails, the tolerated load increases as displacement increases, until it reaches 650 kg, which is more than what was observed in the previous panel. In this case, the entire applied load is again tolerated by elastic Kevlar fibers.

This type of panels also shows an elastic behavior; that is, they go back to their initial situation if unloaded. Maximum load is higher in this panel than the previous one, because fibers bear more loads. The farther the fibers from the neutral axis of the bending test, the more load is applied to them, and as they have higher strength, they bear more load. Like the previous panel, bridging and pull-out does not occur in the improved panel, and the crack grows all over the panel immediately after initiation. After the initial failure, the gypsum matrix bears no load; the entire load is applied to the fibers.

A comparison of different gypsum composite panels reinforced with Kevlar fibers is brought in table. As can be seen, by changing the strengthening mechanism, high strength can be obtained using a low percentage of fibers. In the last panel, there has been and 80% reduction in the usage of fibers, where the strength has only been reduced by 6% in comparison with the composite panel reinforced with chopped fibers.

5. CONCLUSIONS

1. Usage of Kevlar fibers distributed homogenously in gypsum panels increases the bending strength and also the toughness of these panels.
2. Polymer fiber consumption is reduced to a high extent in laminated composite panels.
3. Toughness of laminated composite panels is much higher than that of composite panels with chopped fibers.
4. The process for fabricating improved laminated composite panels is the easiest of them all, and though fiber consumption is much lower, their strength is close to that of short fiber composites.
5. Laminated composite panels show an elastic behavior after crack initiation in the matrix.
6. High strength, high toughness, flexibility and elastic behavior after being unloaded are important characteristics of laminated gypsum composite panels.

REFERENCES

1- Hatami-Marbini H., Pietruszczak S., “On inception of cracking in composite materials with brittle matrix”, *Computers and Structures*, 2007; 85: 1177-1184.

2- Hernandez Olivares F, Bollati M.R, del Rio M, Parga-Landa B., “Development of cork-gypsum composites for building applications”, *Construction and Building Materials*, 1999; pp. 179-186.

3- Li G., Yu Y., Zhao Z., Li G., Li C., “Properties study of cotton stalk fiber/gypsum composite”, *Cement and Concrete Research*, 2003; 43-46.

4- Rio Merino M., Santa Cruz Astorqui J., Hernandez Olivares F., “New prefabricated elements of lightened plaster used for partitions and extrados”, *Construction and Building Materials*, 2005; pp. 487-492.

5- Park S. J., Seo M. K., Ma T. J., Lee D. R., “Effect of Chemical Treatment of Kevlar Fibers on Mechanical Interfacial Properties of Composites”, *Journal of Colloid and Interface Science*, 2002; 252:249-255.