Journal of Engineering Sciences, Assiut University, Vol. 36, No. 3, pp.647-655, May 2008

ADVANCED INTERACTION OF HIGH TENSILE PERFORMANCE OF THIN PLATE COMPOSITES FERROCEMENT - GROUTED MORTAR

***Mahmoud A. WAFA*[1] *and Kimio FUKUZAWA*[2]**

[1]*Post Doctor Fellow, Urban and Civil Engineering Dept., Ibaraki University, Japan / Lecturer, Civil Eng. Dept., Faculty of Engineering, South Valley University, Aswan, Egypt.*

[2]*Professor, Urban and Civil Engineering Department, Ibaraki University, Japan.*

(Received March 8, 2008 Accepted March 24, 2008)

Ferrocement is ideally suited for thin structural elements because of the uniform distribution and dispersion of reinforcement, which provides higher durability, tensile strength and tensile ductility. The aim of this research paper is to study the advanced interaction of high tensile performance of thin plate composites ferrocement-grouted mortar. The present paper deals with the effectiveness numbers of ferrocement wire mesh reinforcement layers as a low and high percentage of ferrocement reinforcement of thin plate grouted mortar specimens on the tensile load-deformation behavior, crack width/spacing, the first crack tensile load, ultimate tensile load and tensile strain capacity. The results clarify that the use of ferrocement wire mesh reinforcement layers with the grouted mortar considerably improves the service and ultimate tensile crack behavior of the thin plate composites, irrespective of the number of ferrocement wire mesh reinforcement layers used. Thus, the ferrocement-grouted mortar composites is considered as a promising material solution to the global structure deterioration problem and tensile ductility are the most important properties of this type of material.

KEYWORDS: *ferrocement wire mesh reinforcement layers, grouted mortar, service and ultimate tensile crack behavior, tensile ductility.*

1. INTRODUCTION

Concrete as building material is characterized by good workability, high compressive strength and low costs. Two characteristics, however, have limited its use: it is brittle and weak in tension. To carry the forces arising by tensile load an adequate reinforcement is required. In practice steel structures are satisfactorily but requires corrosion protection while concrete structures are subjected to severe environmental conditions such as bridge decks, marine structures, ….etc. With entering a new era when the construction industry faces an additional challenge: how to build concrete structures that are environmentally more sustainable and have a good serviceability. Alternatively ferrocement wire mesh can be used as reinforcement. One of the main advantages is that they do not require any protection against corrosion resulting in either the possibility of low concrete covers or other corrosion reasons. Definition of ferrocement reported by ACI Committee 549, 1997 that the ferrocement is a form of reinforced concrete using closely spaced multiple layers of wire mesh and/or small diameter rods completely infiltrated with, or encapsulated in, mortar [1]. The most common type of reinforcement is steel wire mesh to produce elements of small thickness, high durability and resilience and, when properly shaped, high strength and rigidity [2-4]. Additional advantages of a well built ferrocement construction are the low weight with easy of construction, maintenance costs and long lifetime in comparison with other constructions. With the rapid progress of innovative construction technique, application of the ferrocement is increasingly becoming more common for use in various structural engineering applications. These thin elements can be shaped into structural members such as shell, folded plate structures, wall panels, post-tension structural elements, flanged beams (e.g. box beams and I-beams), ….etc. In addition to the previous applications, there are many other uses of ferrocement as structural materials being explored throughout the world. These include: permanent forms for conventional concrete construction, biogas digesters, floor decks, swimming pools, water towers, and small deck bridges [5,6].

So, studying the properties of uses the ferrocement as structural materials are urgently needed, and the literature on the tensile performance of the thin plate composites of the ferrocement-grouted mortar as structural elements is scanty. The parameters that influence the behavior of ultimate tensile load and tensile load-deformation behavior are numerous. This paper presents an investigation of some of these parameters. Therefore, the main objective of the present paper is to amplify our knowledge of the advanced interaction of high tensile performance of thin plate composites ferrocement-grouted mortar. The present paper deals with the effectiveness numbers of ferrocement wire mesh reinforcement layers as a low and high percentage of ferrocement reinforcement of thin plate grouted mortar specimens on the tensile load-deformation behavior, crack width/spacing, first crack tensile load, ultimate tensile load and tensile strain capacity.

2. EXPERIMENTAL PROGRAM

The experimental program was designed to check the high tensile performance of thin plate composites ferrocement-grouted mortar. For this purpose a thin plate composites ferrocement-grouted mortar had a 520 mm total length with 40 x 10 mm cross-section reinforced with a plain weaving ferrocement stainless steel square wire mesh layers were tested in direct tension test, as shown in **Fig. 1**.

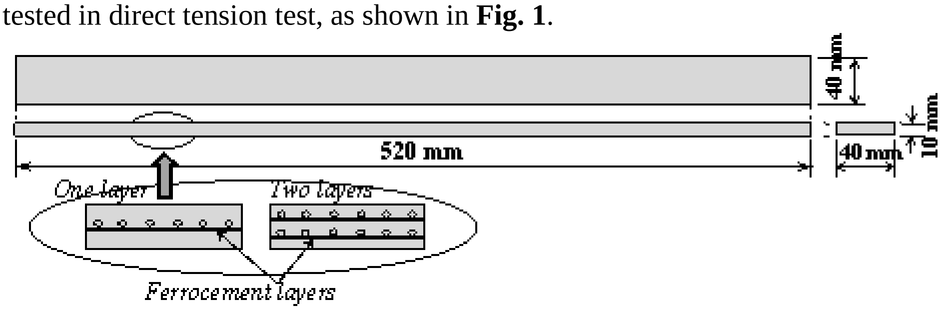


Fig. 1: Thin plate composites ferrocement-grouted mortar

The specimens were arranged in two groups depending on the number of ferrocement wire mesh reinforcement layers as a low and high percentage of ferrocement reinforcement. In the first group, the numbers of ferrocement layers were one and two layers as a low percentage of reinforcement, the second group with four and five layers as a high percentage of ferrocement reinforcement, with three replication of each were tested in direct tension test, as shown in **Table 1**.

Tensile load-deformation behavior, crack width/spacing, first crack tensile load, ultimate tensile load and tensile strain capacity were observed. The crack pattern and failure mechanism were also studied.

Table 1 Thin plate specimens reinforced with ferrocement wire mesh layers

First group (I):

Specimens	**No. of ferrocement layers**	**Low percentage of ferrocement reinforcement**
TP-FL①	1.0	1.11 %
TP-FL②	2.0	2.23 %

Second group (II):

Specimens	**No. of ferrocement layers**	**High percentage of ferrocement reinforcement**
TP-FL④	4.0	4.45 %
TP-FL⑤	5.0	5.57 %

2.1 Materials and Mortar Mix

The grouted mortar mix was specially designed to have a high workability and high compressive strength of about 75 MPa according to the guidelines of ACI Committee 549, 1997 for design and construction of ferrocement [1]. A grout material used supplied by a Japanese corporation was NS Grout (Non-Shrink Grout) in a free flowing powder with light gray color and 2.14 specific gravity containing well graded aggregates, special hydraulic cement, and special cementitious binder were chosen to be mixed with water. The grout mix with water as per water-powder ratio as 0.14 to obtain a homogenous grout with the flow rate of about 20 to 30 seconds (Flow Cone) and when cured, appears similar in appearance to concrete.

For reinforcement, a plain weaving stainless steel square ferrocement wire mesh with closely spaced, as shown in **Photo 1**, was used in the ferrocement thin plate test specimens. The properties value of the plain weaving stainless steel square wire mesh of the three identical specimens were measured as follows: the wire mesh had a diameter of 0.9 mm and a spacing of 5.45 mm with an equivalent yield tensile strength (350 MPa) and ultimate tensile strength (850 MPa). Drinking water was used for the mix preparation of the ferrocement thin plate test specimens.

2.2 Specimen Preparation and Casting

Due to the small thickness of the ferrocement thin plate test specimens that had the 520 mm total length with 40 x 10 mm cross-section, the ferrocement wire mesh reinforcement as one, two, four and five layers were placed almost at mid thickness. Practical difficulties were met when trying to disperse the reinforcement of the ferrocement wire mesh layers in a uniform pattern through the depth of the thin plate test specimens. For a hardened properties of grouted mortar mixture, the following test specimens were cast in steel moulds: three grouted mortar cylinders 50x100 mm for compressive strength, three grouted mortar cylinders 50x100 mm for splitting tensile strength and three prisms 40x40x160 mm for flexural strength. All specimens were demoulded after 24 hours of casting and stored in water at 20 ^{o}C for curing until testing.

2.3 Specimen Testing and Setup

The grouted mortar compressive strength, splitting tensile strength and flexural strength tests were conducted by testing three identical specimens of each test. In addition, the direct tension tests of the thin plate composites ferrocement-grouted mortar that had the 520 mm total length with 40 x 10 mm cross-section were conducted on a 500 KN Universal Testing Machine after 28 days by testing three identical thin plate test specimens of each case. The setup of the thin plate specimens under direct tension test is shown in **Photo 2**.

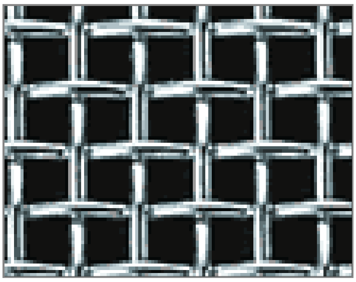


Photo 1: Plain weaving stainless steel square ferrocement wire mesh

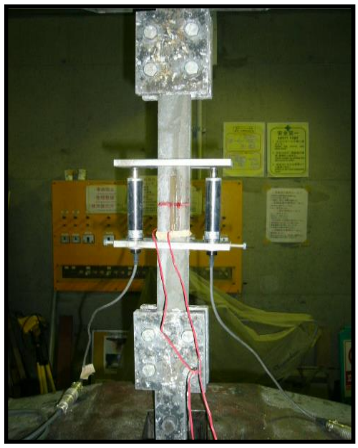


Photo 2: Setup of ferrocement thin plate specimen under direct tension

The effective length of the ferrocement thin plates to be tested was 300 mm with 40 x 10 mm cross-section and both ends of the ferrocement thin plate specimens were attached to two steel machine plates through 8 high tension bolts, (gypsum paste was used before connecting the bolts at both ends between test specimen and machine plate), then the two end of the steel machine plates were fixed to the upper and lower heads of the testing machine. The tensile load-deformation behavior was measured in the middle third of test specimens (100 mm) using linear variable displacement transducer (LVDT) in both edge sides and electrical wire strain gauge on the two opposite faces in the tensile direction of each specimen, as shown in Photo 2. The tensile load was measured using an electric load cell 50 KN capacity. The tensile load-deformation data were collected using a data acquisition system. The system is equipped with a computer module that controls data collected from all channels. The data acquisition system was connected to a desktop computer used to analyze, download, and store the collected data. During loading of each specimen, careful inspection was carried out for observing the initial hair cracks at both sides of specimen. At failure, the crack width/spacing and the ultimate tensile load of the test specimens were observed and recorded.

3. RESULTS AND DISCUSSION

The results obtained from the experimental investigation are tabulated in tables and the comparisons are presented in form of graphs and bar charts. All values are the average of the three identical specimens tested in each case during the testing program of this research paper. The results are discussed as follows.

3.1 Grouted Mortar Property

The grouted mortar mixture used in manufacturing the ferrocement thin plate test specimens was specially designed to have a high workability and high compressive strength of about 75 MPa. The mechanical properties of the grouted mortar as compressive strength, splitting tensile strength, flexural strength and modulus of elasticity values of the control specimens at age of 28 days are given in **Table 2**.

Table 2 Hardened properties of grouted mortar

Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)	Modulus of elasticity (GPa)
75	4.8	9.5	28.5

3.2 Testing of Ferrocement-Grouted Mortar Thin Plate Composites

A ferrocement-grouted mortar thin plate composites was tested in direct tension test with an effective length of 300 mm and 40 x 10 mm cross-section, as shown in **Photo 2**. The two tensile strain values monitored on the two opposite faces of each specimen are very close to each other up to about 80–85% of failure load as well as all specimens were tested successfully with more than 90% of the specimens have cracked firstly in the middle third of the effective length of the specimen. This demonstrates that the test method adopted in the present study is effective in minimizing the eccentricity of the tensile load under direct tension test.

3.2.1 Tensile crack behavior

The tensile behavior of load–elongation curves of middle third of thin plate specimens reinforced with different numbers of ferrocement wire mesh layers as a low and high percentage of ferrocement reinforcement are shown in **Fig. 2**. As can be seen from **Fig. 2**, the tensile crack behavior of the ferrocement thin plate specimens can be characterized by three distinct phases:

Phase 1: Pre-cracking stage

Both materials are elastic, and the tensile load–elongation curves are linear with the tensile load. In this stage, the tensile load is carried mainly by the grouted mortar matrix.

Phase 2: Multiple cracking stage

The salient feature of the tensile cracking behavior of ferrocement-grouted mortar thin plate specimens is that the resisting load drops down right after first cracking, probably due to initial slip of ferrocement wire mesh reinforcement layers at crack plane, and then starts to increase due to structurally effective ferrocement reinforcement layers in tensile region. Multiple cracking starts after the cracking of the grouted mortar matrix. During this stage a transfer of tensile load from grouted mortar to the ferrocement reinforcement layers takes place. The ferrocement reinforcement layers elongate under additional tensile load, thus transferring the tensile load back to the grouted mortar matrix, thereby producing new cracks.

Phase 3: Failure stage

Failure stage is indicated by intensification of existing cracks with the increase of tensile load. Here, the tensile load is carried mainly by the ferrocement wire mesh reinforcement layers. The ferrocement thin plate specimen undergoes rapid increase in tensile elongation, and cracks can extend wide through the cross-section. Such a situation does not take place with grouted mortar specimen without reinforcement, in which, the contribution of the ferrocement wire mesh reinforcement layers at all three stages had a significant effect. Thus, **Fig. 2** indicates that the ferrocement-grouted mortar thin plate specimens reinforced with low and high percentage of ferrocement reinforcement exhibit higher resistance especially after larger elongation.

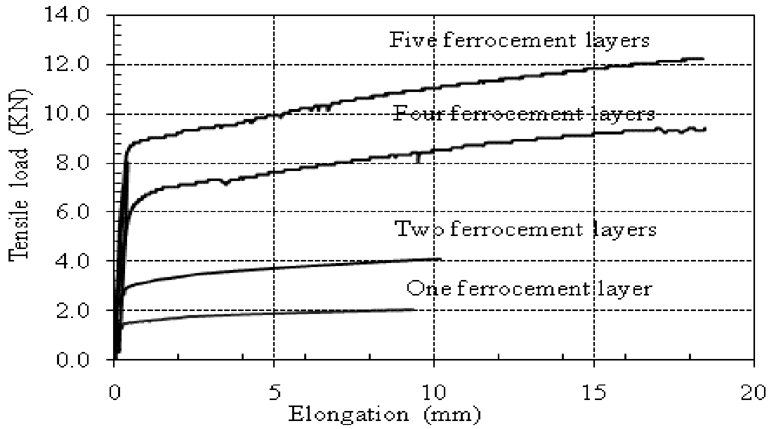
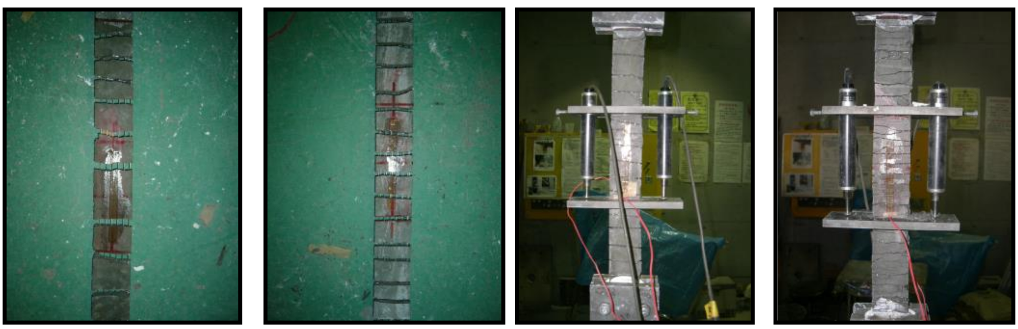


Fig. 2: Tensile load-elongation curves of ferrocement-grouted mortar thin plate composites

Therefore, the presence of the ferrocement wire mesh reinforcement layers had profound effect on the tensile crack behavior at all three stages. Cracking is delayed, multi-cracking stage elongated, and a distinct failure stage could be identified. **Photo 3** shows the tensile crack pattern of the ferrocement-grouted mortar thin plate composites.



One layer Two layers Four layers Five layers

Low percentage of ferrocement reinforcement High percentage of ferrocement reinforcement

Photo 3: Tensile crack pattern of ferrocement-grouted mortar thin plate composites

It is clearly seen that the crack pattern of the ferrocement-grouted mortar thin plate composites is influenced by the presence of ferrocement wire mesh reinforcement, irrespective of the number of ferrocement reinforcement layers used as well as have the ability to reduce cracks width/spacing of thin plate grouted mortar specimens have either low or high percentage of ferrocement reinforcement. Therefore, the results clarify that the use of ferrocement wire mesh reinforcement layers with the grouted mortar considerably improves the service and ultimate tensile crack behavior.

3.2.2 First crack tensile load and ultimate tensile load

The first crack tensile load is the tensile load at which first visual crack appears on the soffit of the ferrocement thin plate specimens. **Fig. 3** illustrates that the effective of addition the ferrocement wire mesh reinforcement layers to thin plate grouted mortar specimens as a low and high percentage of ferrocement reinforcement on improvement of both first crack tensile load and ultimate tensile load.

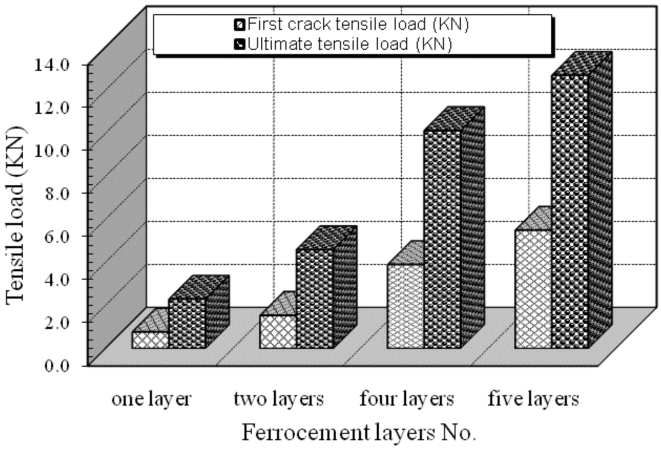


Fig. 3: Effect of ferrocement layers No. on the first crack tensile load and ultimate tensile load

From the investigation of this figure it is clear that; the highest increase of the 1st crack tensile load has been achieved by using the ferrocement wire mesh reinforcement layers. In order to improve the inner bond, the increase of the ultimate tensile load, as achieved with increasing the number of ferrocement wire mesh reinforcement layers, is also a main criterion. In addition, the ferrocement thin plate specimens have reached to the ultimate tensile load level after sufficient warning; because of extended elastic range of the ferrocement wire mesh reinforcement layers is that dependent mainly on the number of wire mesh layers.

3.2.3 Tensile Strain Capacity

Typical tensile stress–strain curves of the ferrocement-grouted mortar thin plate specimens recorded from direct tension tests adopted in this study are shown in **Fig. 4**. When a symmetrical un-cracked ferrocement-grouted mortar thin plate specimens is loaded in tension, the tensile load is distributed between the ferrocement wire mesh reinforcement layers and grouted mortar in proportion to their respective stiffness (E-modulus) of the specimens determines this linear part of the tensile stress-strain curves, as shown in **Fig. 4**.

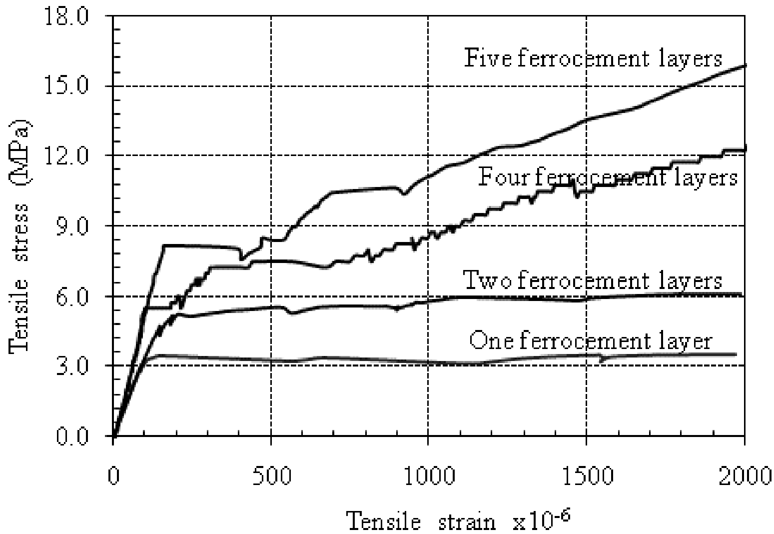


Fig. 4: Tensile stress-strain curves of ferrocement-grouted mortar thin plate composites

It is observed that the numbers of ferrocement wire mesh reinforcement layers have a pronounced effect on the tensile strain capacity of thin plate grouted mortar test specimens. Therefore, the ferrocement-grouted mortar composites referred to as high performance composite materials that developed multiple cracks under tensile load in contrast to single crack and tension softening behavior. Multiple cracking provides a mean of energy dissipation at the material level and prevent catastrophic fracture failure at the structural level, thus contributing to structural safety and service tensile behavior. Meanwhile, material tensile strain hardening (ductility) has been gradually recognized as having a close connection with structural durability by suppressing localized cracks with large width. Many deterioration and premature failures of structures can be traced back to the brittle nature of concrete. Thus, the ferrocement-grouted mortar composites is considered as a promising material solution to the global structure deterioration problem and tensile ductility are the most important properties of this type of material.

4. CONCLUSIONS

The results clarify that the ferrocement wire mesh reinforcement layers with the grouted mortar composites considerably improves the service and ultimate tensile crack behavior of the thin plate specimens, irrespective of the number of ferrocement wire mesh reinforcement layers used as well as have the ability to reduce cracks width/spacing and have a pronounced effect on both the first crack tensile load and ultimate tensile loads level after sufficient warning that have achieved the advanced interaction of high tensile performance of thin plate composites ferrocement-grouted mortar. Thus, the ferrocement-grouted mortar composites is considered as a promising material solution to the global structure deterioration problem and tensile ductility are the most important properties of this type of material.

5. REFERENCES

1- ACI Committee 549: "State of The Art Report on Ferrocement", Reported by ACI 549-R97, in Manual of Concrete Practice, ACI, Detroit, PP. 26, (1997).
2- Kaushik, S.K., and Singh, S.P.: "Behavior of Ferrocement Composite Columns in Compression", Special Publication of ACI Journal, Vol. 172, pp. 669-682, (1999).
3- Masood, A., Arif, M., Akhtar, S., and Haquie, M.: "Performance of Ferrocement Panels in Different Environments", Journal of Cement and Concrete Research, Vol. 33, pp. 555–562, (2003).
4- Kumar, P.R., Oshima, T., Mikami, S., and Rao, C.B.K.: "High Performance Ferrocement (HPF) under Axial Compression", Proceedings of the Sixth International Summer Symposium Organized by Japan Society of Civil Engineers (JSCE), Saitama, Japan, pp. 29-32, (2004).
5- Memon, N. A., Sumadi, S.R., and Ramli, M.: "Strength and Behavior of Lightweight Ferrocement-Aerated Concrete Sandwich Blocks", Malaysian Journal of Civil Engineering, Vol. 18, No. 2, pp. 99-108, (2006).
6- Mansur, M.A., Maalej, M., and Ismail, M.: "Study on Corrosion Durability of Ferrocement", ACI Materials Journal, Vol. 105, No. 1, pp. 28-34, (2008).

تفاعل الأداء العالي لشد الألواح الرقيقة المركبة من الفرّوسمنت – ومونة الجروت

يُناسبُ الفرّوسمنت بتوزيعة وأنتشار تسليحة المنتظم العناصرِ الهيكليةِ الرقيقةِ تُناسبُاً مثالياً ، وبدورة يُزوّد العناصرِ الهيكليةِ الرقيقةِ متانةَ وقوّة وممطولية عالية الشدّ.
يهدف البحث لمعرفة وفهم تفاعل الأداء العالي لشد الألواح الرقيقة المركبة من الفرّوسمنت - ومونة الجروت تحت تأثير حمل الشدّ المباشر.
يتلخص البرنامج العملي للبحث في تأثيرَ عددِ طبقاتَ شبكةِ تسليح الفرّوسمنت كنسبة صغيرة وأخري عالية مِنْ التسليح على سلوكِ حملِ الشدِّ وتشكل الشد الحادث للألواح الرقيقة المركبة من الفرّوسمنت - ومونة الجروت ، عرض الشروخ والمسافة بينهم ، حملِ الشدِّ عند ظهور أول شرخ ، حمل الشدّ الأقصي وإنفعال الشدّ الأقصيِ للألواح الرقيقة المركبة من الفرّوسمنت - ومونة الجروت تحت تأثير حمل الشدّ المباشر.
تُوضّحُ النَتائِجَ بأنّ إستعمالَ شبكةِ تسليح الفرّوسمنت يُحسّنُ الخدمةَ إلى حدٍّ كبير وسلوكَ الشدّ الأقصي للشروخ للألواح الرقيقة المركبة من الفرّوسمنت - ومونة الجروت ، بصرف النّظر عن عددِ طبقاتَ شبكةِ تسليح الفرّوسمنت. وبذلك تُعتَبَر الألواح الرقيقة المركبة من الفرّوسمنت - ومونة الجروت تقدم حلاً لمشكلة تدهورِ العناصرِ الهيكليةِ وممطولية عالية الشدّ والتي تَعِدُ الأكثر أهميةً لهذه المادّةِ.