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Development of New Detachable Connection for Glass Fiber Reinforced Polymer Considering of Short and Long-Term Behavior

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Abstract

The appearance of many Glass Fiber Reinforced Plastic (GFRP) constructions look like ordinary steel construction, because GFRP has been imitated by the same way with the traditional steel's cross section as well as connection system. In terms of detachable connection, there was not enough appropriate option of GFRP connection, such as a traditional bolt connection for steel and wood structures. Most of all, from material characteristic of GFRP related to the deficient ductility, the shear-stress principle of GFRP is not proper for the material property, which causes ineffective and not economic application of material.

With this research problem, the innovative and detachable connection system, which is more considered with appropriate material characteristic for GFRP, is developed. Not only short time but also long time research with various connection variations is carried out.

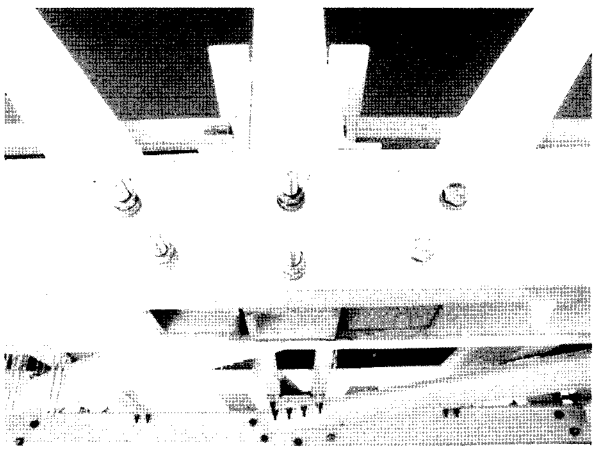
Keywords : Glass fiber reinforced polymer (GFRP), Detachable connection, Appropriation for the material involved, Form-fit-connection system, Long-term behavior, Creep, Pre-stressed bolt

1. Introduction

The structural material, namely glass fiber reinforced polymer (GFRP) is focused on structural field. However, the lack of GFRP connection technology produces only an imitation of steel and timber structures and a problem which needs a specific solution. With this motivation the author would like to research a new detachable GFRP connection system appropriate for the material involved and adopt a membrane structure (Fig. 5).

From several of real projects of GFRP-construction, the author was able to see that the GFRP bolt connection system has been used as a normal steel one. (Fig. 1)

In the material aspect, however, GFRP is totally



〈Fig. 1〉 A typical GFRP joint looks alike steel bolted joint

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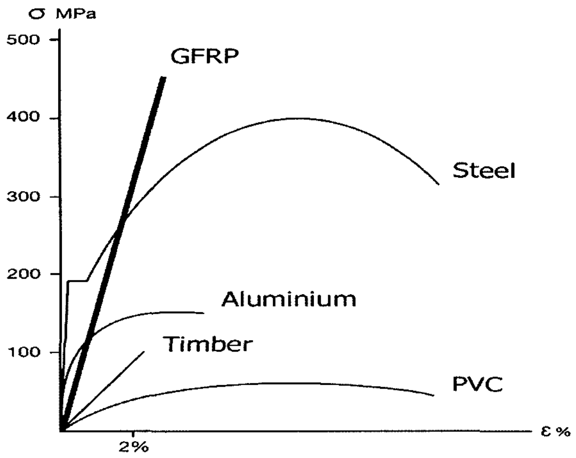
different from steel. Steel is isotropic material, but GFRP is anisotropic material, that is, it depends on the direction and structure of the glass fiber. The stress-strain-diagram shows the different characteristics, refer to the material failure: Steel has a distinctive plastic yield behavior, but GFRP shows linear deformation until the ultimate load (Fig. 2, 3).

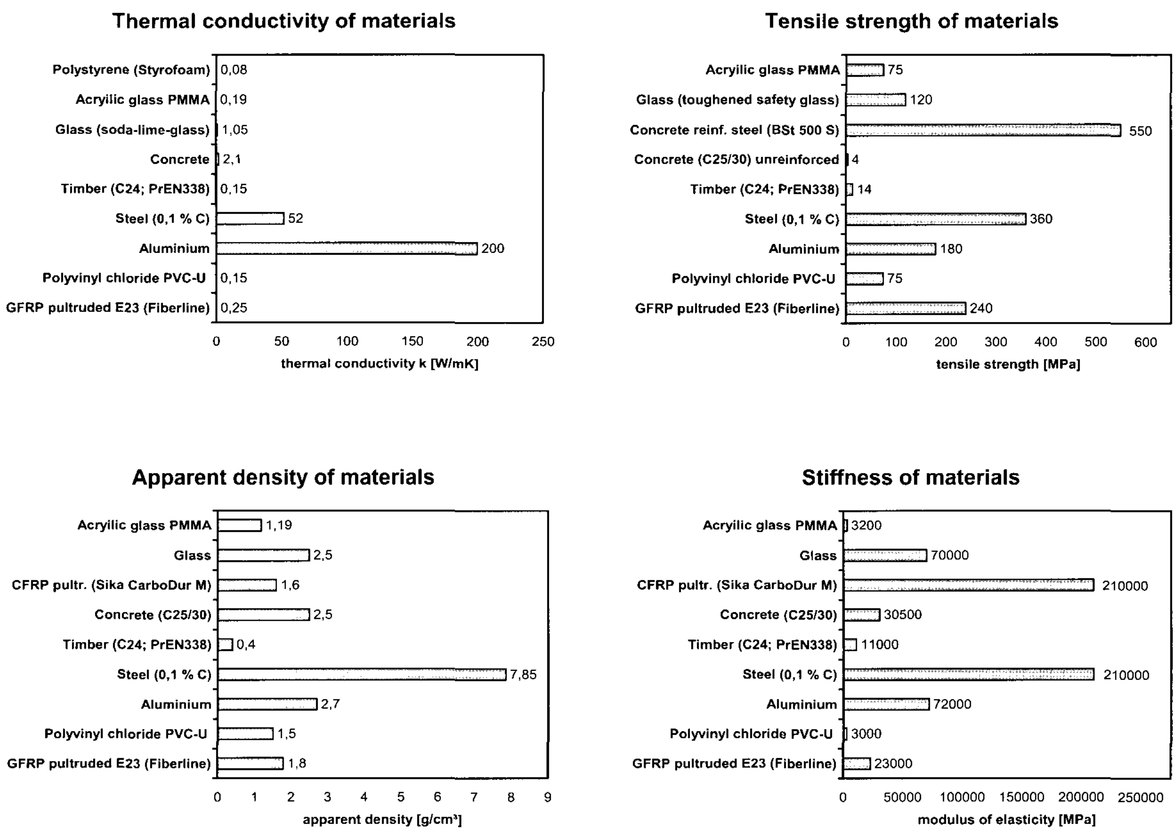


〈Fig. 2〉 Stress and strain diagram

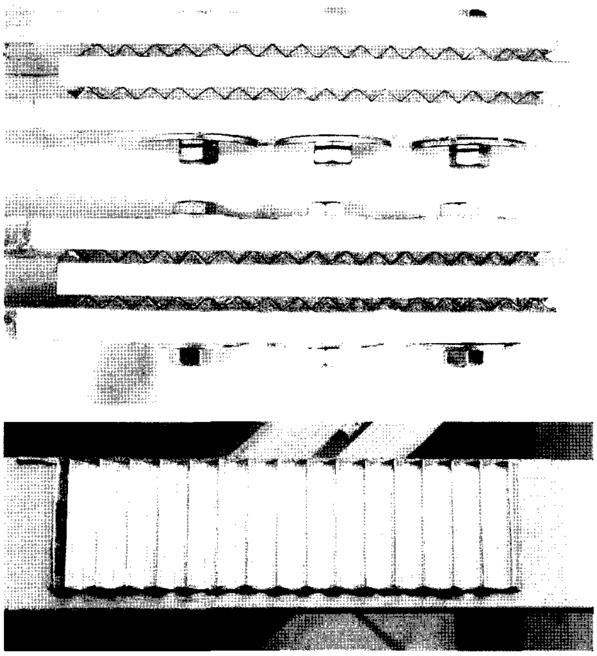
Thus, a conventional GFRP connection, just an imitation of bolt connection system from steel or timber, needs an own innovative joining system, which is able to transfer the load more effectively, and suitable applications considering GFRP are also absolutely needed.

2. The New GFRP Connection System

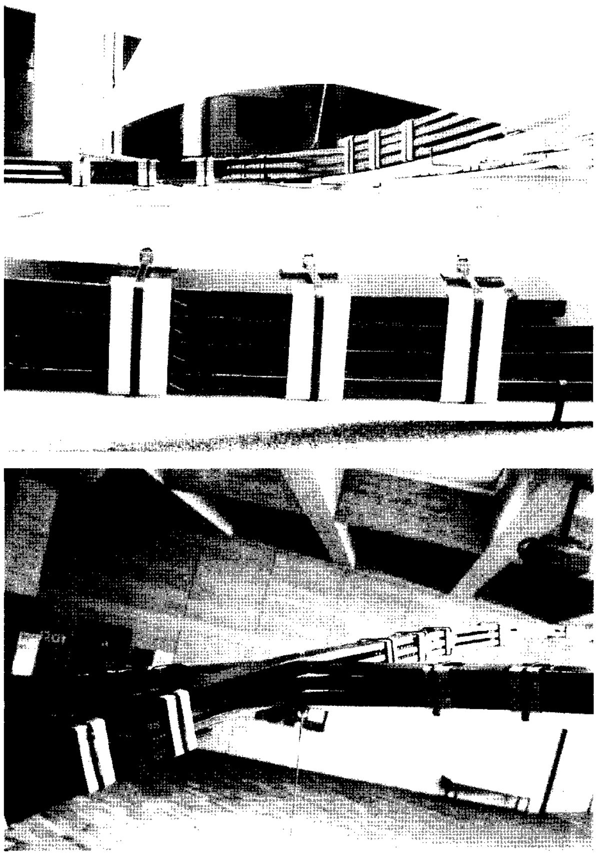
The new GFRP connection system, that the authors have developed (Fig. 4, 5), has many mechanical advantages. The force and material characteristics etc. can be more effectively transferred to the whole body of the element than the normal bolt connection through the new GFRP system using an epoxy bond, which has excellent mechanical stability and durability. It covers the disadvantages of steel bolt connections as well as welding, namely uneconomical



〈Fig. 3〉 Characteristics of GFRP and other building materials



〈Fig. 4〉 Examples of new GFRP connection "form fit connection"



〈Fig. 5〉 Form fit connections of GFRP membrane pavilion

structural design and an enormous amount of labor in-situ, which doubtlessly adds to the cost and time of construction. Shown in this figures are, however, the new detachable GFRP connection system, which provides that the people can build the system as easily as possible with the material advantages, lightness and anti-corrosive characteristics. It makes a distinguished temporary modular structure, which can assemble the structure and remove on the various places.

In order to use this system for real construction, the research of GFRP considering the material characteristics should be continued.

The adhesive structures are currently in need of a specially suited way, which means that most of the structures using bond are highly influenced by circumstances, such as a cleanness of bonded part and dried air in a working place. Moreover, the adhesive connection is not any more detachable.

Even if the conditions would be perfect for a GFRP connecting system, the significant key issue is how total structures can be delivered from the factory to the worksite, because a certain volume of structures are limited in delivery by traffic regulations. That is doubtlessly why high costs and time of adhesive construction are required as usual. Thus, all of difficulties emphasize the need of research for a GFRPs connecting system.

As far as a GFRP connecting system is concerned, the authors have been researching the new and innovative connection design and the general behavior of structures with a GFRP connection. As the authors mentioned before, one of the significant merits of the new GFRP connection, which can be probably named as a saw connection, is that the load can be evenly transferred and it produces structures with a small number of bolts.

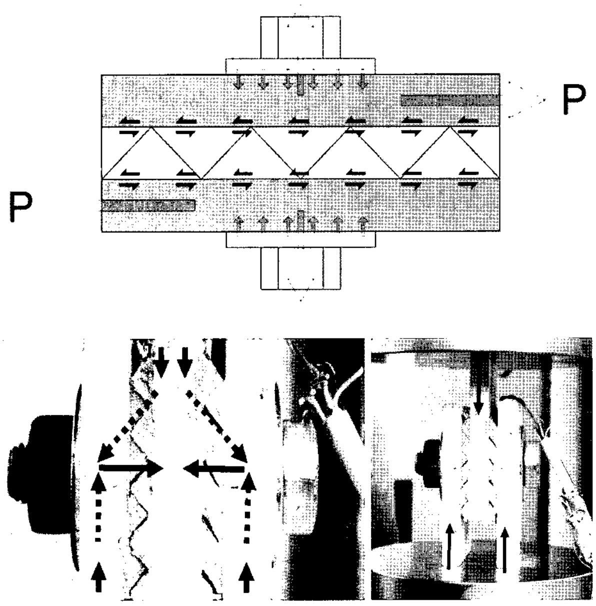
Due to the new system, most of all, the surplus of materials and unsuitable structural designs can be eliminated, and finally, it can also result in an economical structure.

3. Experimental Model

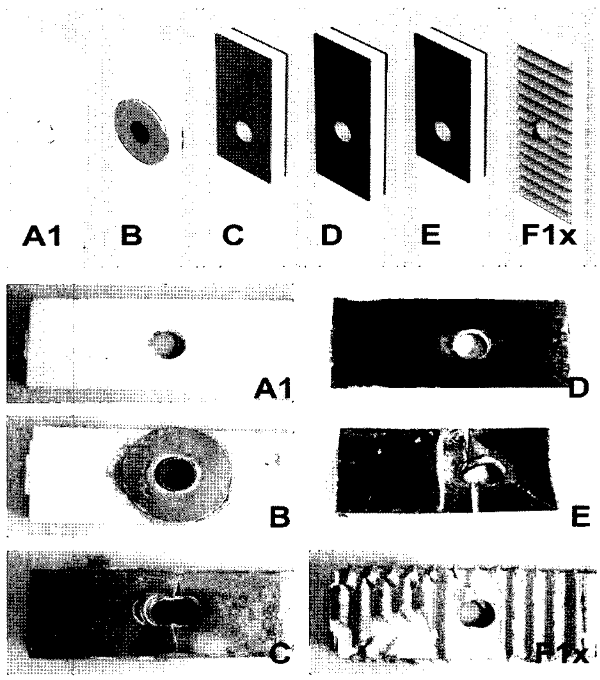
As the author mentioned above, the cross section of GFRP is made out of an anisotropic material, such as timber, which the allowed stress of the main fiber direction is approximately three times stronger than that of any other direction, because the common GFRP cross section is fabricated through a pultrusion system in the main fiber direction, parallel to the profile direction. Moreover, in the case of concentrated load, for example, the whole of the bolt in the GFRP section shows a critical weakness, thus, causing the most failure in the connection (Fig. 7, 10).

In order to cover the material weak point of a GFRP connection, the surplus connection should have been designed before now. This effect, of course, can also result in not only an uneconomical structure but also in a design that is not optimal. With this problem, the realization of the practical design of a GFRP connection is being delayed, and it points clearly out that an imitation of steel and timber structure is not any more effective for a GFRP connection. Nevertheless, the most of the GFRP connections currently have been designed with just a simple bolt system, because there are not enough connection technologies, that consider the characteristics of GFRP, and there are also not enough experiences with the GFRP adhesive technologies in structural design, e.g. long-term behaviors. Especially, the lack of experimentation for the deformation and strength of adhesive joints causes complications in working conditions and the incredible laws of construction. With these problems, in this research, the variable experiment is carried out, in order to understand the behavior of element failure and the element ability of load translation.

The first experimental-test series was focused on the investigation of reinforcement of detachable bolt-connection, in order to compare to the loading capacities of various possibilities with reinforced materials. (Fig. 7) The first of the tested connection is the simple bolted GFRP-joint without reinforcement (A1). Second, GFRP-profile is reinforced with bonded



〈Fig. 6〉 Principle of load flow in "form fit connection" with a bolt



〈Fig. 7〉 Tensile test specimen and failures pictures steel sheet in involved part (C). Third, GFRP is reinforced with bonded CFRP (carbon fiber reinforced polymer) strips (D, E).

Fourth, only the hole of the bolt is reinforced with bonded steel ring-element (B). Fifth, the "Formschlussverbindung" (form-fit-connection) (F1x), similar to the tooth of a saw, is attached on the element of GFRP.

The fifth (Fx1), "form-fit-connection", shows the highest failure load. (Fig. 8) The test result shows very clear the load bearing behavior. From the first to the fourth specimen, it shows obviously not only low load capacities but also smaller stiffness than last one (form-fit-connection).

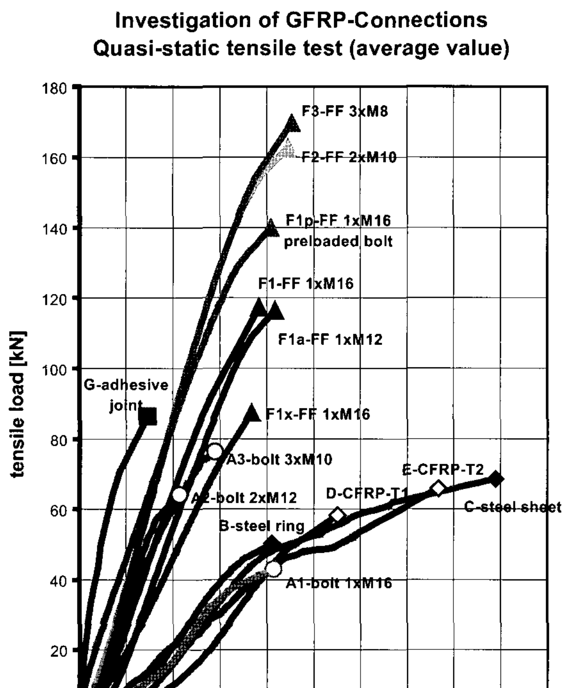
Based on the principle of force transfer from the form-fit material, the form-fit-connection, regarding load bearing capacity, is very clear distinguished from the other connecting systems.

The four variations, which are performed with load bearing behavior, show the shear-stress behavior through the bolt, regardless with reinforced material, so that the force was transferred to concentrated load. (Fig. 7)

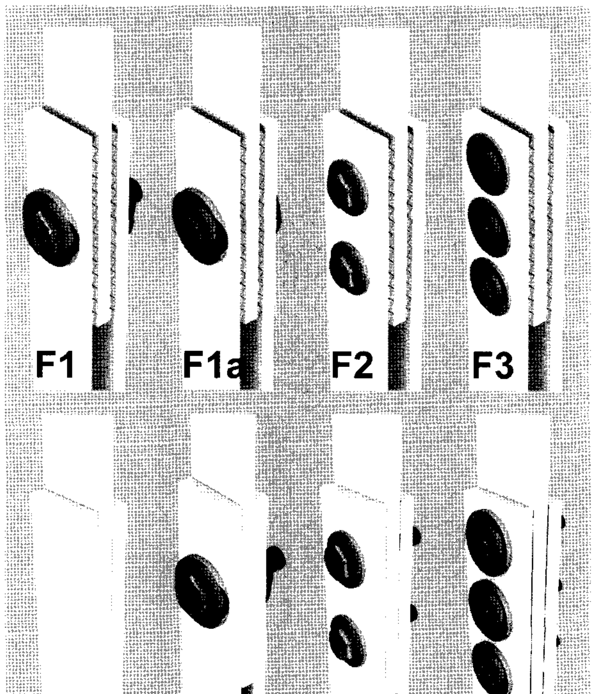
This load behavior would cause the failure of structure, due to a little ductility and plastic load reverse, and most of all, it means that GFRP is not appropriate material with concentrated load.

The significant characteristic of the "form-fit-connection" is that the load is very effectively transferred to the whole elements. Before the local adhesive element is destroyed, the bolt just takes a simple tensile force without shear force (Fig. 6), which can result small dimension of bolt. Comparing a traditional bolt connection, it is very important advantage for economical aspect as well as aesthetic point of view.

The further experiments, based on this result, were performed with four kinds of connection models.



〈Fig. 8〉 Quasi static tensile test of GFRP Connections



〈Fig. 9〉 Experimental specimen of further tensile test series

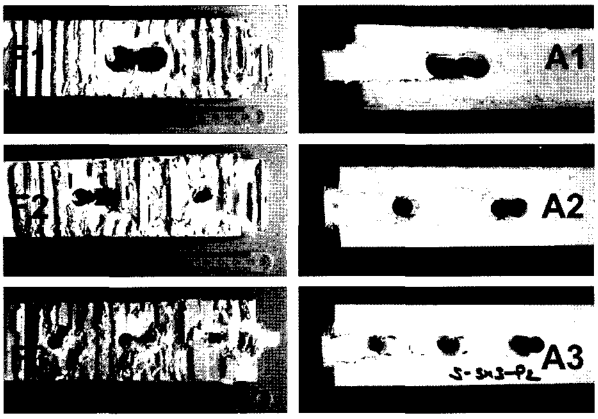
- adhesive bonded joint (G)
- form-fit-connection with bolt (F1, F2, F3)
- form-fit-connection with pre-stressed bolt (F1p)
- bolted joint (A1, A2, A3)

With the form-fit-connection, the number and allocation of bolts were varied. The tests were performed with one to three bolts. (Fig 9)

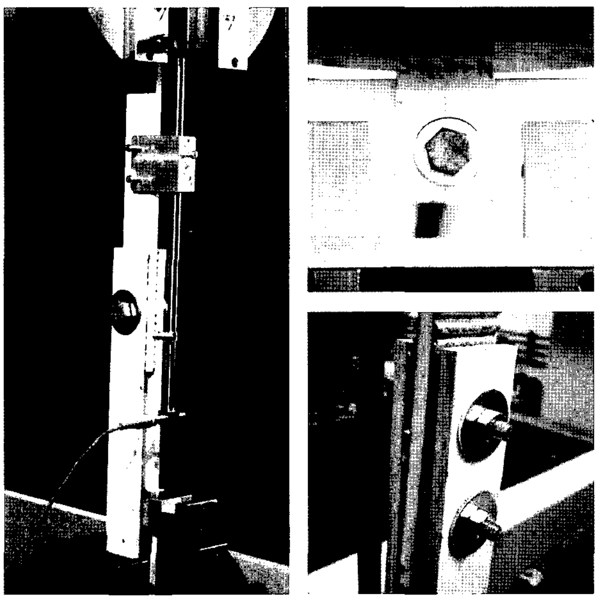
From the experiment, Fig. 8 shows that the "form-fit-connection" has a material strength as well as a high failure load and stiffness. Fig. 8 shows that the adhesive joint with an epoxy bond has the highest stiffness value, but a "form-fit-connection" presents the top value of failure load. With the additional pre-stressed bolts, the form-fit-connection shows 15 or 20% higher load capacity.

In particular, through the graph, the selection of a new connection is very suitable for a GFRP element. In the sense of anisotropic material, research of the GFRP connection will be a very interesting issue.

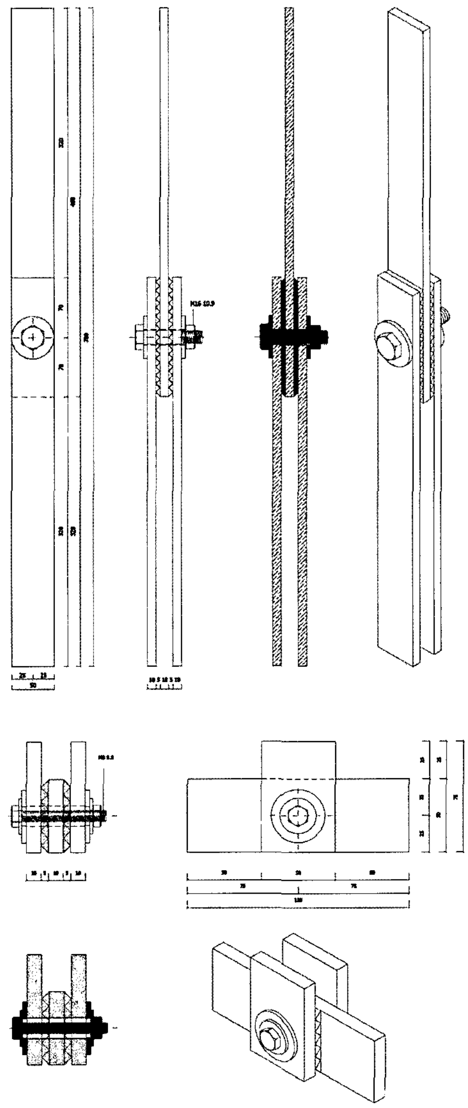
Then, based on the above results, the whole experimental elements were produced combining a "form-fit-connection" and an epoxy adhesive



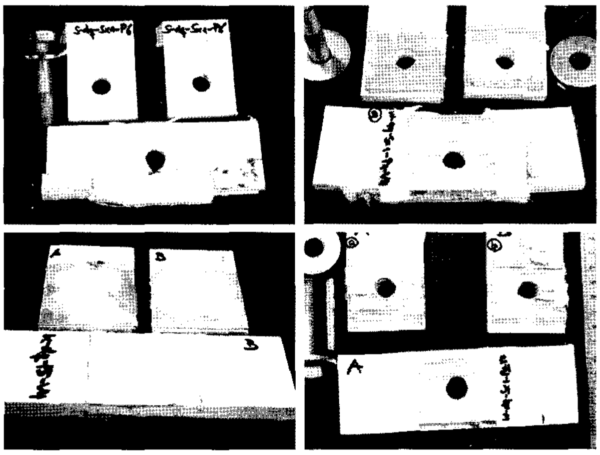
〈Fig. 10〉 Failures of GFRP sections at connection comparison form fit and bolted connection



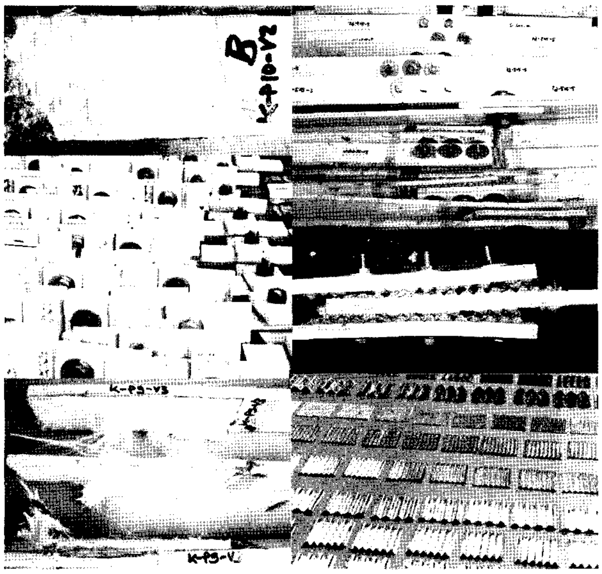
〈Fig. 11〉 View of quasi static short term experimental test



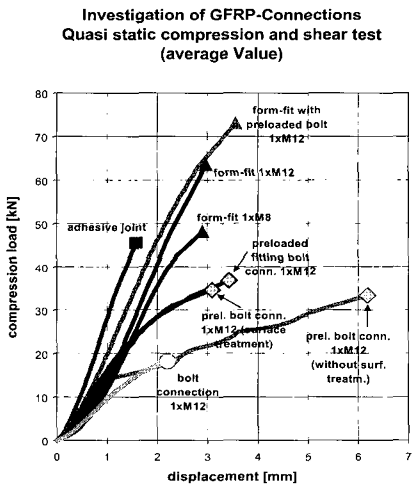
〈Fig. 12〉 An example of the tensile and compressive experimental models



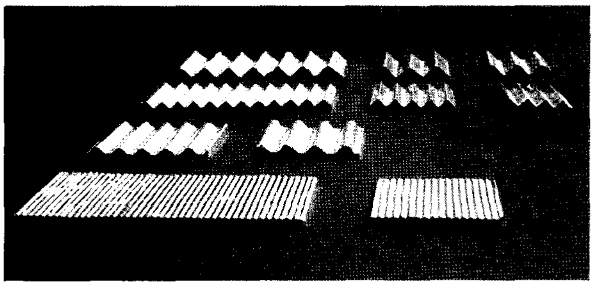
〈Fig. 13〉 Compression and shear test failures pictures



〈Fig. 14〉 Parts of experimental elements



〈Fig. 15〉 Quasi static compression test of GFRP Connections



〈Fig. 16〉 Precast art of form fit connection

and adopted "GFRP pavilion" directly (Fig. 5).

In order to keep the intellectual property, a patent right was submitted to the German Intellectual Property Office in 2004, 2005 and 2006.

For a further development, the application of various connecting form might be also a great approach and advantage, and in this sense, the tensile, compression and shear test would be considerable. (Fig. 11, 12, 13, 14, 15)

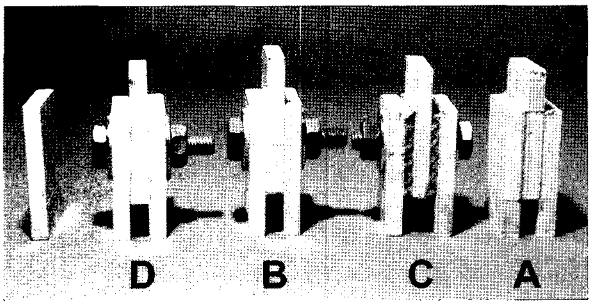
The test results show the advantages of form-fit-connection, comparing the other connection variations.

Moreover, regarding to fabrication, this form-fit -connection was optimized. Fig. 16 shows the prefabricated precast part of form-fit, which can be subsequently bonded on the GFRP surface, and from this process, the advantage of fabrication can be expected.

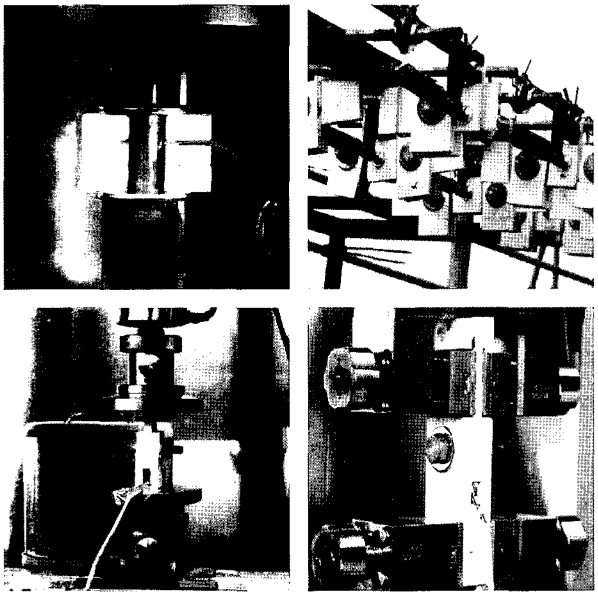
4. Long-term investigations

In reality, it is not enough to investigate just only short -term test, in order to adopt to real GFRP construction. Therefore, in this research, besides short-term-test, long-term-test was performed.

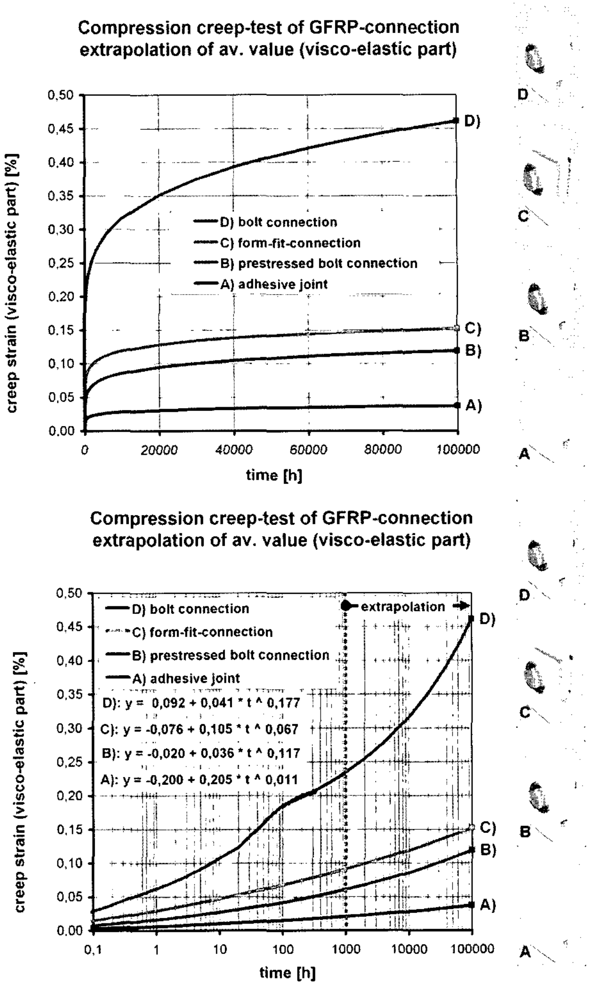
The load bearing behavior of form-fit-connection with bolt application could be determined by short-term-test. The most organic polymer material, such as a glass fiber reinforce plastic (GFRP), which has the tendency toward material creep, includes very important meaning, especially for GFRP connection,



〈Fig. 17〉 Experimental specimens of compression creep test series



〈Fig. 18〉 View of long term investigations (inside and outside)



〈Fig. 19〉 Results of long term Investigations of GFRP Connections

because the long-term-behavior of GFRP connection could run different from short-term one. Thus, the long-term sustainability for connection design should be significantly considered. At first, the creep and relaxation test was performed.

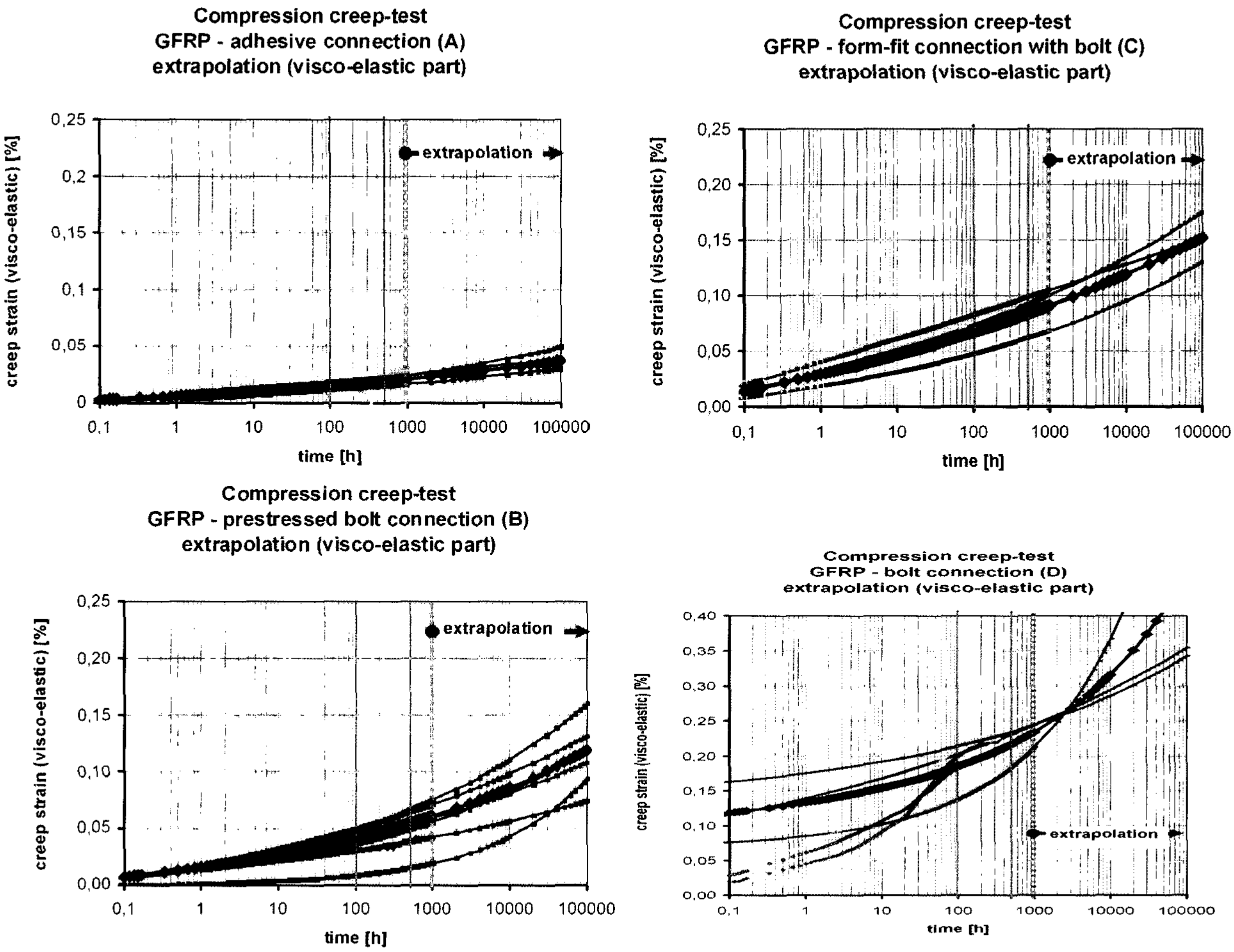
The test specimens are (Fig. 17):

For the long-term test, the small specimens were used, and the 1000 hours load tests were performed with each three to six tests.

In the diagram, the result curves were measured with average values of till 1000 hours, and to estimate for from 1000 till 100000 hours (11.4 years). The curves show the creep's deformations with the visco-elastic parts, and the results were extrapolated, according to Findley-Function. (Fig. 19, 20)

However, the extrapolated values of bolt connection (D) had to be very limited, because there was an amount of scattering of the values. (Fig. 20)

The result shows that the form-fit-connection (C) had the obviously larger stiffness than the bolt connection (D), not only in the real values of test but also in the extrapolated one. In addition, the adhesive bond joint was the firmest variation, even though it is not detachable style and not an expected goal of research as well. For a further research, the author would highly recommend to the connection



〈Fig. 20〉 Extrapolation of creep behavior

with pre-stressed bolt as a specialized point. According to the short-term investigation, the connection with pre-stressed bolt could increase a significant high load level and connecting stiffness. In fact, due to the creep behavior of GFRP as a matrix material, the pre-stress of slip joint for civil engineering has not been classified and applied, while the same connection with the appropriate conditions has been used in another industries, such as a air-craft and auto motive's industry.

Furthermore, there is little results of research from the "GFRP with pre-stressed bolt", which has been only dealed with a general term of average value.

However, several research of civil engineering shows that the connection system with pre-stressed bolt can be adopted to GFRP real construction, related to material characteristic and enduring, if the condition and process of measurement are suitable. In addition, not only the treatment of surface and optimization of basic material but also the optimized initial pre-stress of fine adjustment and the exact calculation's method of pre-stress are also included.

From the result of this research, the author could investigate that the form-fit-connection is the most effective and the most appropriate connection in GFRP, especially related to long-term behavior with pre-stressed bolt.

5. Conclusion

The author has developed the new advanced form-fit- connection system considering GFRPs characteristics. From the short-term and long-term experiments, the author has discovered that the new form-fit-connection can play the prominent mechanical roll, instead of the imitation of steel bolt connection. In terms of the new GFRP connection system, the author would like to research temperature influences, further long-term -behaviors and dynamic problems. At the same time, the developments of further joint variants considering specific material characteristics, GFRP, will be designed. Based on the results of above research, the actual research project will be subsequently demonstrated. Most of all, the connection system with pre-stressed bolt will be also continued.

References

1. Knippers, Jan/ Park, Don-U/ Hub, Alexander/ Hwang, Kyung-Ju: "The mobile und modular GFRP-membrane-structure with the new innovative connection", in Journal of the Korea Association for Shell and Spatial Structures, vol. 5, no. 2, pp. 7-15, Jun 2005.
2. Knippers, Jan/ Park, Don-U: "Stabile Plastiken, Fussgeangerbruecken aus faserverstaerkten Kunststoffen", in db Deutsche Bauzeitung, May 2002.
3. Park, Don-U/ Hwang, Kyung-Ju: "Structural Design using GFRP", in Journal of the Korea Association for Shell and Spatial Structures, vol. 5, no. 1, pp.20-26, Mar 2005.
4. Park, Don-U: "Materialgerechte loesbare Verbindungen bei glasfaserverstaerkten Kunststoffen" in 2. Forschungsforum: Faserverstaerkter Kunststoff von der Entwicklung zur Anwendung. Tagungsband. Hrsg. FOMEKK, Bauhau-Universitaet Weimar, DLR, Institut für Tragkonstruktionen und Konstruktives Entwerfen (ITKE), Unversitaet Stuttgart. Weimar: Bauhaus Universitaet, 2004.
5. Park, Don-U/ Hub, Alexander/ Hwang, Kyung-Ju/ Knippers, Jan: "The new developments of smart and lightweight structures with glass fiber reinforced polymer (GFRP) in architecture and structural engineering", in POAR People & Architects, vol. 113, pp. 82-95, Sept 2005
6. Carmona, Martin/ Fischinger, Michael: "Seminararbeit Neue Werkstoffe und besondere Tragwerke SS 2003", Institut für Tragkonstruktionen und Konstruktives Entwerfen (ITKE), Universitaet Stuttgart, 2003.
7. Gabler, Markus: "Entwicklung und Erprobung von verstaerkten Bolzenans chluessen", Diplomarbeit, Institut für Tragkonstruktionen und Konstruktives Entwerfen (ITKE), Universiteat Stuttgart, 2003.
8. Yesilova Buelent: "Untersuchungen von Verbindungstechniken bei glasfaserverstaerkten Kunststoffen", Diplomarbeit, Institut für Tragkonstruktionen und Konstruktives Entwerfen (ITKE), Universiteat Stuttgart, 2006.
9. Findley, William/ Lai, James/ Onaran, Kasif: "Creep and Relaxation of Nonlinear Viskoelastic Materials", North-Holland Publishing Company -Amsterdam New York Oxford, 1976
10. Rotheiser, Jordan: "Joining of plastics, Handbook for designers and engineers", Carl Hanser Verlag München Wien und Hanser Gardner Publication Cincinnati, 1999
11. Rosner, Charles/Rizkalla, Sami: "Bolted Connections for Fiber-Reinforced Composite Structural Members: Experimental Program" in Journals of Materials in Civil Engineering pp 223-231, ASCE, Nov 1995
12. Matthews, F. L.: "Theoretical Stress Analysis of Mechanically Fastened Joints" in Joining fibre-reinforced plastics pp 65-103, Elsevier Applied Science, London and New York, 1987

13. Bikermann, J. J.: "The Science of Adhesive Joints", Academic Press, New York, 1968
14. Prabhakaran, R./ Robertson, J.: "An Experimental Investigation of Load-Sharing in a Multi-Bolt Pultruded Composite Joint", in Second International Conference on Composites in Infrastructure (ICCI), Tucson, Arizona, USA, vol. 2, no. 1, pp. 355-368, Jan 1998.
15. McClure, Ghyslaine/ Mohammadi, Yaghoub: "Compression Creep of Pultruded E-Glass-Reinforced-Plastic Angles" in Journals of Materials in Civil Engineering pp 269-276, ASCE Nov 1995
16. Sarabi, Bahman: "Das Anstrengungsverhalten von Polymerwerkstoffen infolge ein- und zweiachsigen Kriechens, Ermittlung von Langzeitbemessungs- kennwerten", Dissertation an der Gesamthochschule Kassel D34, 1984
17. Fiberline Composites A/S: "Fiberline Composites Design Manual 1995"
18. Sika Deutschland GmbH: Technisches Merkblatt Sikadur 30, Sep 2003.