New Material for Reinforced Concrete in Place of Reinforcing Steel Bars

Nouveau matériau remplaçant l'acier dans le béton armé

Ein neues Material an Stelle von Stahl für die Bewehrung von Beton

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SUMMARY
The characteristics of a new material developed to replace reinforcing steel bars are introduced together with experimental results. This non-corrosive, lightweight new material is made of fiber reinforced plastics. It was formed in two – or three-dimensional grid shape and was developed for the purpose of improving the durability of reinforced concrete structures. Examples of applications to actual structures are also described.

RÉSUMÉ
Les caractéristiques du nouveau matériau mis au point à la place des barres d'armature sont présentées, de même que les résultats expérimentaux. Ce nouveau matériau léger et non corrosif est une fibre de plastique renforcée, produite sous forme de grille en deux ou trois dimensions. Il a été mis au point dans le but d'améliorer la résistance des structures en béton armé. Des exemples d'applications pour les structures réelles sont également donnés.

ZUSAMMENFASSUNG
Die Eigenschaften dieses neuen Materials werden unter Verwendung von Versuchsergebnissen näher behandelt. Das aus faserverstärktem Kunststoff bestehende Material zeichnet sich vor allem dadurch aus, dass es nicht korrodiert und leicht ist. Es können zwei – und dreidimensionale Gitterstrukturen hergestellt werden. Das Material wurde mit dem Ziel entwickelt, dem Beton eine bessere Dauerhaftigkeit zu geben. Einige Beispiele praktischer Anwendung werden beschrieben.

1. INTRODUCTION

It is said that the decline in the durability of steel reinforced concrete structures is caused mainly by the rust generated on the reinforcing steel bars. There are two new methods to cope with the rust generation: one is to prevent the concrete from cracking by improving its tensile strength such as fiber reinforced concrete, and the other is to replace the steel reinforced bars themselves with new material. The latter method is adopted, and developed Neo Fiber Material for Concrete (NEFMAC) to replace reinforcing steel bars is introduced in this paper.

2. CHARACTERISTICS OF NEFMAC

This newly developed NEFMAC is made of fiber reinforced plastics (FRP) produced by the filament winding method. Its characteristics are as follows:

(1) Desired strength, modulus and elongation can be obtained by changing the kind and the quantity of the fibers. Phenomena similar to those of reinforcing steel bars at the yield point are observed by combining different kinds of fibers.
(2) Sufficient anchorage to concrete is secured and lapped splice joints are made possible by making NEFMAC in grid shape and obtaining enough strength at the cross points.
(3) It is possible to form NEFMAC into curved surfaces and three dimensional shapes as well as flat surfaces thus making it unnecessary to process and assemble it in the field. And also re-bar arrangement such as diameters and intervals can easily be changed (See Fig. 1).
(4) Fatigue strength is equal to or greater than that of reinforcing deformed bars.
(5) Shear strength is about 50% of tensile strength.

Details of the results are not described in this paper, but it is known that the coefficient of linear expansion of NEFMAC is similar to that of concrete and that NEFMAC is light in weight (specific gravity is approximately 2.0). In addition, using vinyl ester resin as matrix, resistance to alkaline, acid and chemical products were tested and good results were obtained.

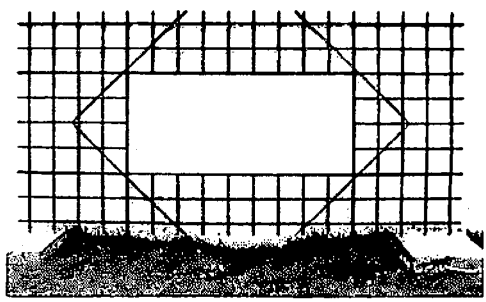


Fig. 1 Sample of NEFMAC

3. EXPERIMENTAL RESEARCH

3.1 Properties of Material

Fig. 2 shows schematically the stress-strain relationship of NEFMAC in cases where various fibers were employed. In this figure, the volume fraction of fibers Vf is taken as 40% for calculation. Examples of NEFMAC using high strength carbon fiber (HSCF), high modulus carbon fiber (HMCF), aramid fiber (AF), glass fiber (GF) and mixtures of the above fibers are shown in the figure. Phenomena similar to those when a reinforcing steel bar yields take place by combining various fibers. Fig. 3 gives an example confirming the above.

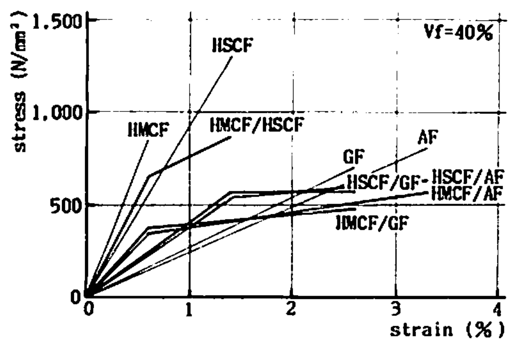
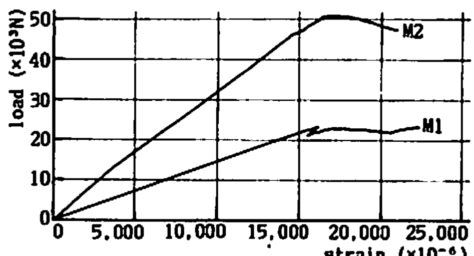


Fig. 2 Schematic stress - strain relationship of NEFMAC



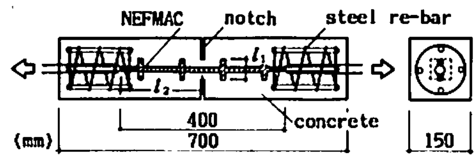
properties of NEFMAC

test piece	fiber	Vf (%)	sectional area (mm²)
M1	HSCF/GF	43.2	36.5
M2	HSCF/GF	42.2	84.1

Fig. 3 Actual load - strain relationship of NEFMAC

3.2 Properties of Anchorage and Lapped Splice Joint

The anchorage properties between NEFMAC and concrete were investigated through tensile tests by using the specimens shown in Fig. 4. In the experiment, the length of transverse reinforcement was taken as a parameter, and the development length of NEFMAC was kept as a constant at 2 intervals of the transverse reinforcement. The experimental results are given in Fig. 5. From Fig. 5 it became clear that anchorage of NEFMAC greater than the tensile strength of the longitudinal reinforcement can be secured by taking the NEFMAC transverse reinforcement as equal to or greater than 30mm and developing it as much as 2 intervals of transverse reinforcement into the concrete.



parameters of specimens

specimen	l_1 (mm)	l_2 (mm)
T1-1,2	30	200
T2-1,2	50	200
T3-1,2	70	200

properties of NEFMAC

fiber	sectional area (mm²)	Vf (%)	tensile load (N)	modulus (N/mm²)
HSCF/GF	84.1	42.2	49.9×10^3	39.6×10^3

Fig. 4 Specimens for the tensile tests

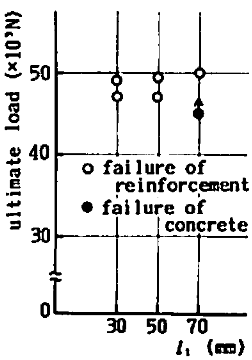
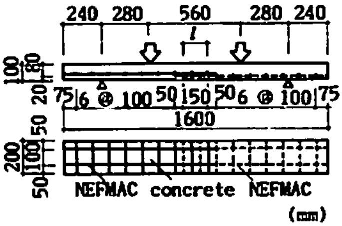


Fig. 5 Ultimate loads of the tensile tests

After the anchorage properties of NEFMAC were confirmed, bending tests of specimens having lapped splice joint were conducted. The shapes of the specimens and the test results are shown in Fig. 6 and Fig. 7 respectively. From these results it was confirmed that with the length of lapped splice greater than 1.0 times the grid size (more than 2 intervals of transverse reinforcements are overlapped), NEFMAC longitudinal reinforcements are broken and therefore lapped splice joints become possible.



parameters of specimens

speci-men	l (mm)	NEFMAC
B-1	50	GF
B-2	100	GF
B-3	150	GF
B-4	50	HMCF
B-5	100	HMCF
B-6	150	HMCF

properties of NEFMAC

fiber	sectional area (mm²)	Vf (%)	tensile load (N)	modulus (N/mm²)
GF	70.8	39.4	45.5×10^3	32.6×10^3
HMCF	88.4	22.6	33.4×10^3	78.1×10^3

Fig. 6 Specimens for the bending tests

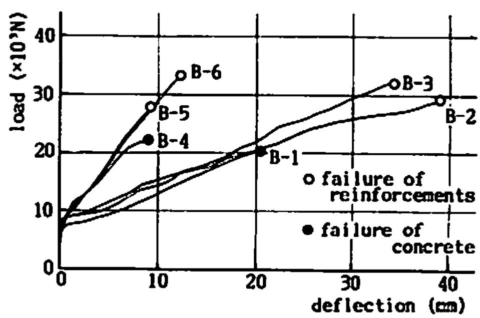
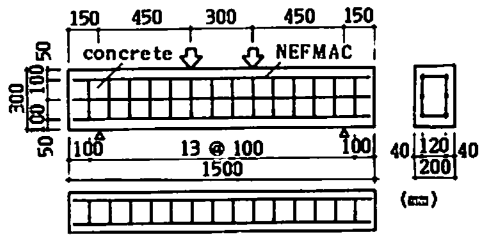


Fig. 7 Load - deflection curves of the bending tests

3.3 Fatigue Properties

Main reinforcements and stirrups of test specimens illustrated in Fig. 8 were formed in three-dimensional shape as shown in Fig. 9. Test specimens were subjected to two-point repeated loading. The test results are shown in Fig. 10. Many specimens were failed due to fatigue failure of main reinforcements at the cross points of stirrups. The fatigue strength of the deformed bars which have the same ultimate tensile load as NEFMAC are also shown in solid and dotted lines [1]. It became clear that the fatigue strength of NEFMAC is equal to or greater than that of deformed bars.



properties of NEFMAC

NEFMAC	fiber	sectional area (mm²)	Vf (%)	tensile load (N)	modulus (N/mm²)
main	HSCF/GF	207.1	25.5	78.6×10^3	27.1×10^3
stirrup	HSCF/GF	112.2	25.5	—	—

Fig. 8 Specimens for the fatigue tests

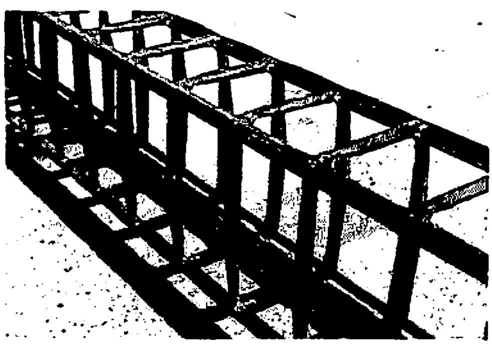


Fig. 9 Sample of three-dimensional shaped NEFMAC

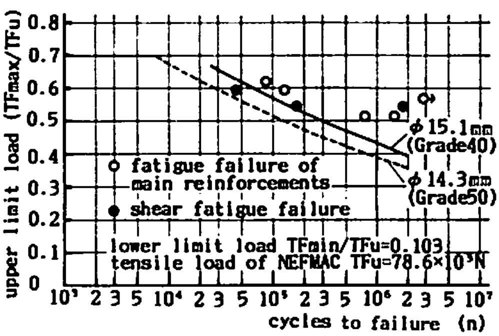
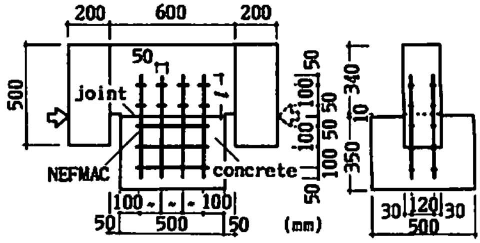


Fig.10 Fatigue strength of NEFMAC

3.4 Shearing Properties

As illustrated in Fig. 11 specimens with NEFMAC arranged in the concrete were produced and shearing tests were conducted. As for parameters in the tests, the development length of NEFMAC and loading program - monotonic or cyclic - were selected (See Table 1). In cyclic loading, the maximum displacements of specimens were controlled equal to the displacement at the 75% load of the maximum monotonic load, and they were forced to fail after 5 cycles. The test results are shown in Table 1. As listed in Table 1, it became clear that the shear strength of NEFMAC is about 50% of the tensile strength under monotonic loading. It also became clear that the development length of NEFMAC is enough to transmit the shearing force when it is 1 interval of the transverse reinforcement and that the shear strength becomes about 80% compared with that under monotonic loading when the specimens are subjected to cyclic loading.



properties of NEFMAC

fiber	sectional area (mm^2)	Vf (%)	tensile load (N)	modulus (N/mm^2)
HSCF/GF	84.1	42.2	49.9×10^3	39.6×10^3

Fig.11 Specimens for the shearing tests

specimen	l (mm)	loading program	Pmax (N)	Pmax/8 (N)
S-1	200	monotonic	196.1×10^3	24.5×10^3
S-2	200	cyclic	156.9×10^3	19.6×10^3
S-3	100	monotonic	194.2×10^3	24.3×10^3
S-4	100	cyclic	156.9×10^3	19.6×10^3

Table 1 Test results of the shearing tests

4. APPLICATION EXAMPLES

Application of NEFMAC to actual structures started in 1986 and there are 7 application cases for tunnel structures in particular. NEFMAC was used as reinforcing grids for shotcrete (See Fig. 12), and as reinforcements for arch and invert (See Fig. 13 and Fig. 14). It was adopted because of following reasons: a corrosion free material was required for a water-conveyance tunnel with flowing high acid water. And even if trouble with corrosion had not existed, NEFMAC, light in weight and requiring no processing or assembling, was best suited for improving the work productivity in a small space such as a tunnel where works depend on manpower.
In addition, application to inshore structures, underground structures and slope protection structures is now being planned.

Fig.12 Reinforcing grids for shotcrete

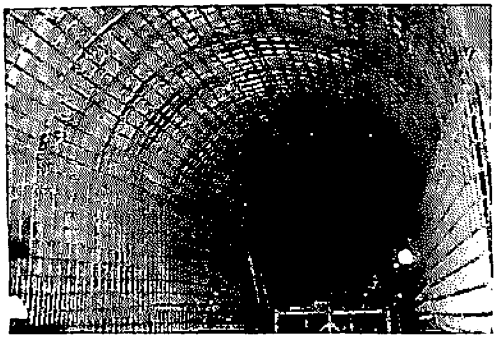


Fig.13 Reinforcements for arch of tunnel

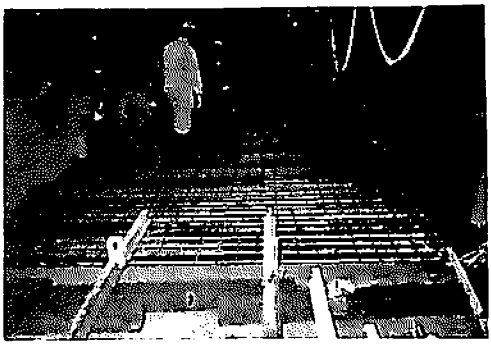


Fig.14 Reinforcements for invert of tunnel

5. CONCLUSIONS

The new non-corrosive, lightweight material --Neo Fiber Material for Concrete (NEFMAC)-- was introduced above and various test results were presented. NEFMAC, developed to replace reinforcing steel bars, is made of FRP that was formed in two- or three-dimensional grid shape to improve the durability of reinforced concrete structures. Confirmation tests on fire resistance are presently underway and it is expected that NEFMAC applications will be further widened in view of the test results.

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REFERENCE

1. Japan Society of Civil Engineers, Standard Specifications for Concrete, 1986.