Challenge Journal of Concrete Research Letters

Research Article

Reinforcement of concrete beams using waste carbon-nanoclay-fiberglass laminate pieces

Zinnur Çelik [a,*], Emrah Turan [b], Meral Oltulu [b], Gülşah Öner [c]

[a] Department of Construction Technology, Pasinler Vocational School, Atatürk University, 25300 Erzurum, Türkiye
[b] Department of Civil Engineering, Atatürk University, 25240 Erzurum, Türkiye
[c] Department of Mechanical Engineering, Atatürk University, 25240 Erzurum, Türkiye

ABSTRACT

In the last few decades, strengthening of structures in need of repair with fiber reinforced polymer (FRP) composite materials produced with different fiber types has gained great importance. Within the scope of this experimental study, the usability of hybrid glass and carbon composite laminates produced for different purposes and later cut into waste was investigated for concrete reinforcement. Hybrid composite laminates were produced in the form of glass-carbon-glass and carbon-glass-carbon, and the effect was investigated in two different sequences in the study. In addition, there are 3 different rates of nanoclay (0.50%, 0.75% and 1.25%) in the production of composite materials, and the effect of nanoclay ratio was investigated. In the study, two different numbers of composite laminates were adhered to the concrete samples produced in 70x70x280 mm dimensions and subjected to flexural strength test. In the Carbon-Glass-Carbon series using triple waste laminate pieces, the highest flexural strength was reported in the CGC-0.75-3 series, which achieved an increase of approximately 55% and 42% compared to the Control and Control-E series. It was determined that the effectiveness of the reinforcement technique of concrete with laminates in flexure did not change significantly depending on the number of laminate pieces. The main mode of failure in the experimental work was due to concrete fracture.

ARTICLE INFO

Article history:
Received 6 May 2023
Revised 10 July 2023
Accepted 26 July 2023

Keywords:
Waste laminate
Carbon-glass-carbon
Glass-carbon-glass
Flexural strength
Retrofitting

1. Introduction

In many existing structures, reinforced concrete structural elements become unable to meet the desired requirements during their service life due to design errors, increased loading, errors in the construction phase or dynamic loads such as wind, earthquake or environmental conditions that will cause aging, corrosion and deterioration (Obaidat et al. 2011; Askar et al. 2022; Hashemi 2011). It is a well-known fact that the insecurity of reinforced concrete structures made of low strength concrete and steel under the effect of dynamic loads. For these reasons, in most buildings that cannot meet the requirements, reinforcement is a more effective and economical solution instead of reconstruction. Reinforced beams can contribute to extending the service life of the structures and increasing the loading capacity, resulting in better performance of the structure (Ghobarah et al. 2002).

In the last century, traditional methods such as jacketing with concrete and steel plates have been used to strengthen reinforced concrete structures. However, one of these traditional methods used, while concrete jacketing increases the element sections and creates an excessive load on the structure, it has some disadvantages in terms of corrosion and application difficulties in steel jacketing (Askar et al. 2022; Raval and Dave 2013; Chalioris et al. 2014; Thermou et al. 2019; Shehata et al. 2009).

Due to the negative consequences of the above-mentioned strengthening methods, the reinforcement of

* *Corresponding author*. Tel.: +90-442-661-3982 ; E-mail address: zinnur.celik@atauni.edu.tr (Z. Çelik)
ISSN: 2548-0928 / DOI: https://doi.org/10.20528/cjcrl.2024.01.001

structural elements such as reinforced concrete beams with Fiber Reinforced Polymers (FRP) has increased significantly in recent years (Ascione and Feo 2000). The reason why FRP composites are preferred can be attributed to their higher performance due to their light weight, high hardness, corrosion resistance and ease of application (Amin et al. 2022a, 2022b; Talikoti and Kandekar 2019). FRP matrices are composite materials reinforced with different types of fibers. There are several types of FRPs: carbon FRP (CFRP), glass FRP (GFRP), basalt FRP (BFRP) and aramid FRP (AFRP). FRP composites are applied to reinforced concrete beams in the form of laminates, rods or fibers by bonding or mechanical anchoring (Hashemi 2011).

Miruthun et al. (2021) investigated the strengthening property of GFRP wrapped in three different ways in their study. The results showed that GFRP laminates improved the strength and ductility properties of the cracked RC beam. Obaidat et al. (2011) show that when beams strengthened using CFRP laminates are structurally efficient in shear and flexure.

In addition, ceramic, carbonaceous, clay, and polymer fillers are used in nano and micro sizes to improve the mechanical, impact and thermal properties of FRP composites (Sharma and Joshi 2023). Rafiq et al. (2017) found an increase of 23% and 11%, respectively, in the peak load and stiffness of the glass fiber reinforced epoxy composite with the addition of 1.5% nanoclay. Khan et al. (2011) showed that the addition of nanoclay to epoxy and CFRP improves the impact and flexural strengths of the composite. In Xu and Hoa (2008) stated that nanoclay added to carbon/epoxy composites in the amount of 2 phr increased the flexural strength by 38%. Öner et al. (2018) showed that the addition of nanoclay to hybrid carbon/fiberglass composites improves the flexural and tensile strength of the composite.

2. Research Significance

Recently, studies of strengthening concrete with glass and carbon fiber are widely seen in the literature. In this research, chopped waste materials consisting of epoxy matrix composite laminates prepared with these two fiber types were used to strengthen the concrete element. Composite materials used in reinforcement were not produced within the scope of this study, they are laminate pieces that were prepared for a different research and then became waste. With the increasing volume of waste, the rapid pollution of the environment poses a significant threat to biodiversity and human health. Consequently, there has been a surge in research efforts focused on waste recycling, both in terms of investigation and implementation (Şengel et al. 2022; Canbaz et al. 2021). Waste composite materials are arranged in two different ways as glass - carbon - glass (G-C-G) and carbon - glass - carbon (C-G-C). In addition, there are 3 different ratios of nanoclay in the content of composite materials. Hybrid waste material differs from concrete reinforcement studies in the literature in terms of both the regulation and use of nanoclay. Since the waste composite material is found in chopped form, its dimensions are smaller than the laminates in the literature. Therefore, the dimensions of the concrete flexural specimen were determined as 70x70x280 mm. The experimental study includes the application of 2 different number of composite laminate materials to the concrete sample using the bonding technique. As a result, the flexural strength of composite reinforced concrete was investigated.

3. Materials and Method

Within the scope of the experimental study, the cement type used in all mixtures is CEM I 42.5R Portland cement. The specific gravity and specific surface area of the cement were 3.12 g/cm^3 and 3486 cm^2/g, respectively. The chemical composition, physical and mechanical properties of cement is shown in Table 1. In the study, 4-25 mm coarse aggregate and 0-4 mm river sand were used as fine aggregate. The specific gravity of fine and coarse aggregates were 2.68 and 2.34, respectively.

Table 1. Chemical, physical and mechanical properties of cement.

Chemical Composition	%	Physical and Mechanical Properties	
SiO_2	19.17	Compressive strength 2 days (MPa)	27.2
Al_2O_3	4.50	Compressive strength 28 days (MPa)	55.6
Fe_2O_3	3.04	Specific surface area (Blaine) (cm^2/g)	3486
CaO	63.08	Specific gravity (g/cm^3)	3.12
MgO	1.78		
SO_3	2.89		
Insoluble materials	0.98		
Loss on ignition	3.93		
Na_2O	0.22		
K_2O	0.63		
CI	0.0116		

In this study, laminates with Glass-Carbon-Glass and Carbon-Glass-Carbon sequences that were used by Öner et al. (2018) and Ünal et al. (2017) in their research and which were later disposed of were used. Carbon (245 g/m²) and E-glass (200 g/m²) fibers and a standard epoxy resin were used in the manufacture of the waste laminates. Nanoclay (0.50%, 0.75% and 1.25%) was added to the epoxy matrix by ultrasonic cavitation mixture. In the related study, the tensile and flexural strength range of the Carbon - Glass - Carbon composite series was determined as 550 MPa to 590 MPa and 908 MPa to 958 MPa, respectively. These range of the values were obtained as 599 MPa - 625 MPa and 794 MPa - 892 MPa for the Glass - Carbon - Glass sequence. The configuration of laminate materials (Carbon-Glass-Carbon) used by Öner et al. (2018) in their studies is presented in Fig. 1.

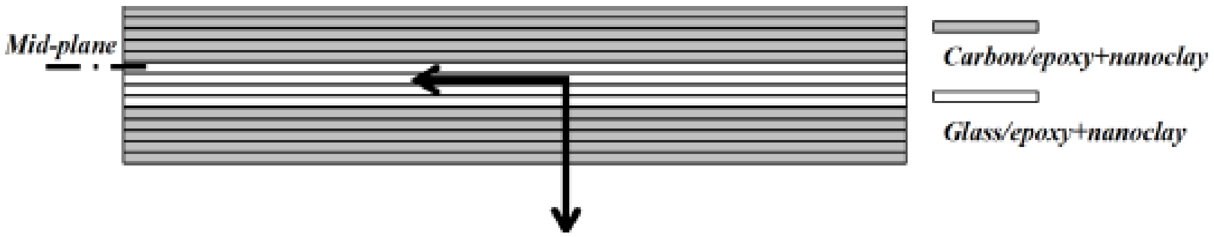

Fig. 1. Configuration of hybrid composite laminate (Öner et al. 2018).

The mixture composition by weight of the concrete used in this study is presented in Table 2. The strength of the concrete samples prepared in this study was aimed to be in the C40/50 class. The water-cement ratio was kept constant as 0.45 in all concrete samples and a 1.2% superplasticizer was used to obtain workability. These ratios were determined as a result of preliminary experiments.

Table 2. Amount of materials in 1 m³ of concrete.

Materials	Amount (kg)
Cement	400.00
Water	181.40
Super Plasticizer	4.80
0-2 mm	510.26
2-4 mm	264.65
4-8 mm	331.14
8-16 mm	381.70
16-25 mm	165.94

In the study, 3x3x20 mm waste laminate pieces with G-C-G and C-G-C sequences were adhered to the midpoint of the 70x70x280 mm concrete beam samples with the help of epoxy. In addition, laminate pieces were tested by gluing them to the concrete beam in 2 different numbers (3 and 7). In order to ensure the surface contact of the beam with the epoxy, the beam surfaces are cleaned of dust and sawdust with the help of a compressor. It was applied to the epoxy surfaces with a roller to obtain a thickness of 0.8-1 mm. Laminates were adhered to the surface of the beams (Fig. 2).

Control and laminate reinforced 28-day beam samples were subjected to 3-point flexural test in accordance with TS EN 12390-5 (2010) standard. Each sample was named according to the arrangement, nanoclay ratio and number of laminates used. For example, in a CGC-0.50-3 code, the first three letters (CGC) represent the carbon-glass-carbon sequence, the number 0.50 represents the nanoclay ratio in the laminate, and 3 represents the number of laminate. In addition, only the epoxy bonded control group is symbolized as Control - E.

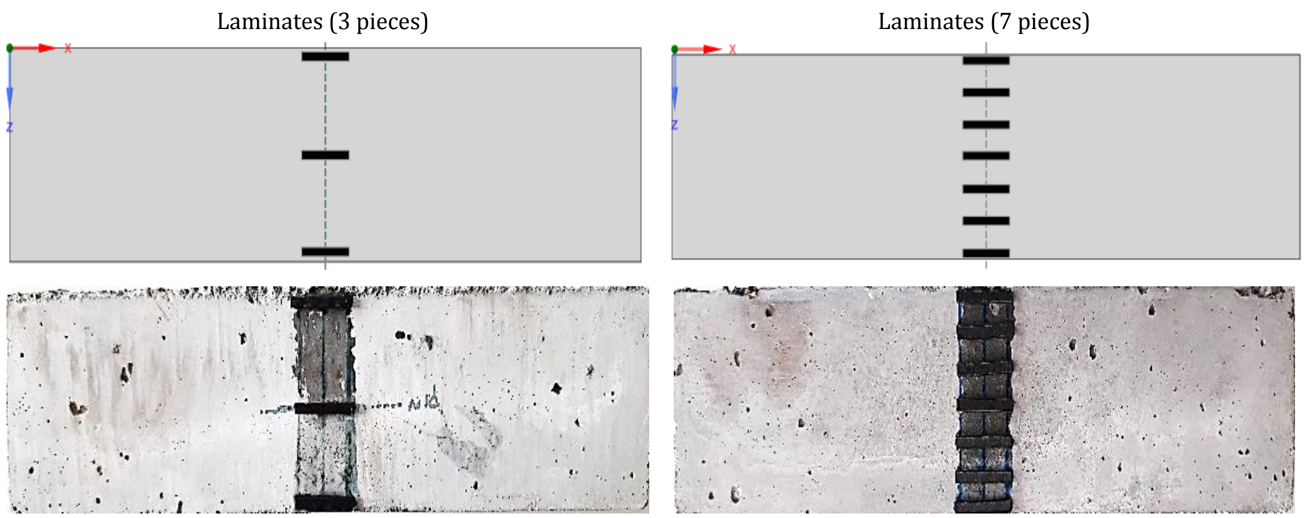

Fig. 2. Laminate-adhered concrete specimens.

4. Results and Discussion

4.1. Workability

The slump test on the concrete to which the laminate pieces were attached was carried out in accordance with TS EN 12350-2 (2010). The slump value of the produced concrete was determined as 18.8 cm. This value provided the S4 class values, one of the consistency classes given in the TS EN 206-1 (2021) standard.

4.2. Flexural strength

The flexural strength results of concrete reinforced with 3 and 7 pieces of Carbon-Glass-Carbon laminate are given in Fig. 3. The mean values for flexural strength of concrete to the series without nanoclay were published in previous study by Turan et al. (2023).

When Fig. 3 is examined, the lowest flexural strength value was obtained from the control sample with 5.59 MPa. An increase of 9.12% was observed in the flexural strength of the Control-E series, which was produced by adhering only epoxy to the control sample, compared to the control sample. The highest flexural strength in the triple array Carbon-Glass-Carbon series was obtained from the CGC-0.75-3 group with a value of 8.69 MPa. This value was 55.46% and 42.46% higher compared to the Control and Control-E sample, respectively. The flexural strength of CGC-0.75-3 and CGC-1.25-3 groups of Carbon-Glass-Carbon series with nano clay added was higher than the series without nano clay (CGC-0) addition. In the C-G-C series with nanoclay reinforced with three pieces of laminate, the highest concrete flexural strength was calculated in the group with 0.75% nanoclay. Obaidat et al. (2011) used CFRP laminates to retrofitting reinforced concrete beams in their study. The increase in the maximum load of shear force and flexural strength of the laminate reinforced samples reached values between approximately 23% and 33%, respectively.

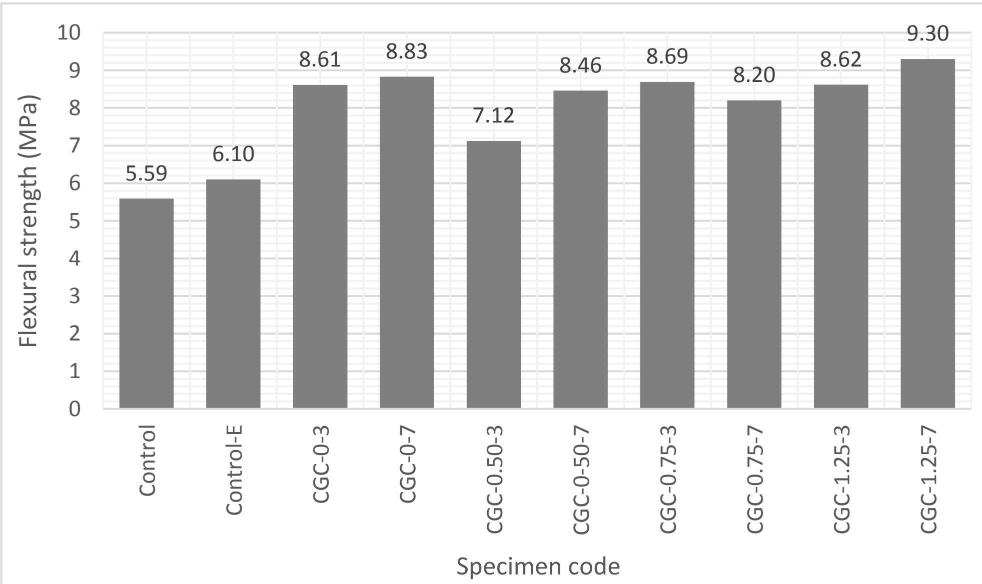

Fig. 3. Flexural strength of concrete reinforced with 3 and 7 pieces of CGC laminate.

In the CGC series with 7 laminate pieces, the highest concrete flexural strength value was obtained from the CGC-1.25 series with 9.30 MPa. This value was 66.36% and 52.46% higher than the flexural strength of the Control and Control-E series, respectively. It was determined that the flexural strength of CGC-0-7, CGC-0.50-7 and CGC-0.75-7 series increased by 44.75%, 38.68% and 34.42%, respectively, compared to the Control-E sample.

The flexural strength results of concrete reinforced with 3 and 7 pieces of Glass-Carbon-Glass laminate are given in Fig. 4. The flexural strength values of the Glass-Carbon-Glass series reinforced with 3 laminates were calculated in the range of 8.08 MPa - 8.84 MPa. The highest flexural strength in the triple array Glass-Carbon-Glass group was obtained in the GCG-0.75-3 series with 8.84 MPa. This value detected in the GCG-0.75-3 series was 58.14% and 44.92% higher compared to the Control and Control-E groups, respectively. The flexural strength of the series containing 0.50%, 0.75% and 1.25% nanoclay was determined to increase by 6.43%, 9.40% and 8.17%, respectively, compared to the GCG-0-3 series without nanoclay.

The flexural strength values of the 7-arrays Glass-Carbon-Glass series were calculated in the range of 8.45 MPa - 9.09 MPa. The highest flexural strength value was obtained from the GCG-0.75-7 series with an increase of 49.02% compared to the Control-E series. Compared to the flexural strength of the Control-E sample, an increase of 40.32% and 42.62% was detected in the GCG-0-7 and GCG-0.50-7 series, respectively. Although the flexural strength of the 1.25% nanoclay-containing GCG series decreased, it was 38.52% higher than the Control-E series. In the GCG-0.50-7 and GCG-0.75-7 series, 1.63% and 6.19% increase in flexural strengths were reported compared to GCG-0-7, respectively.

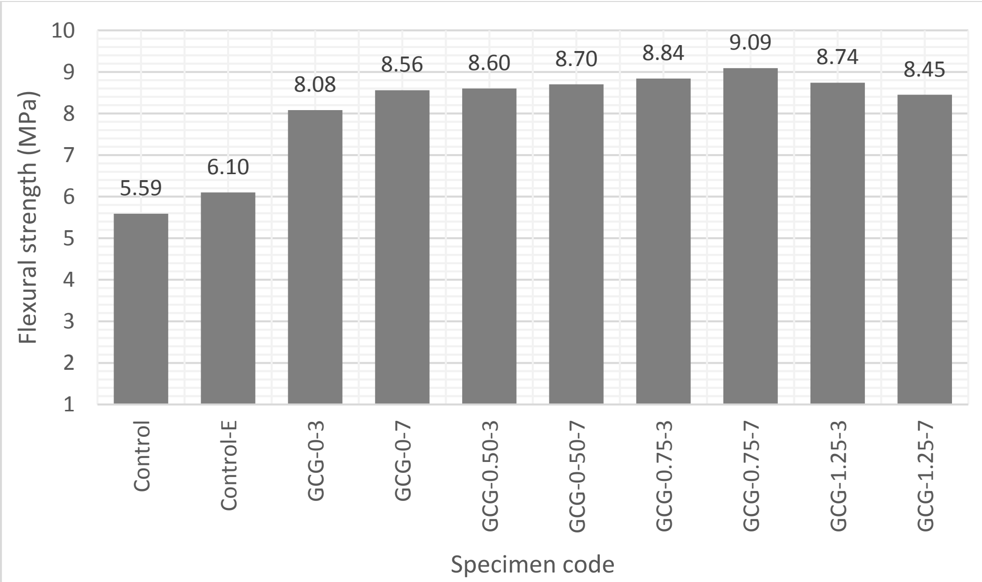

Fig. 4. Flexural strength of concrete reinforced with 3 and 7 pieces of GCG laminate.

As a result of examining together the CGC and GCG series used in triples, the highest flexural strength values in nanoclay added samples were obtained from the GCG series. In addition, the optimum value in terms of nano clay was determined as 0.75% in both arrays (CGC-GCG) strengthened with 3 pieces of laminate, and the addition of 1.25% nanoclay decreased the flexural strength in both groups. This is attributed to the increase in the viscosity of the epoxy and the amount of air bubbles during the mixing process due to the increased amount of nanoclay used (Xu and Hoa 2008). These results are similar to the tensile and flexural strength results of the laminates in the Öner et al study, where the waste material was obtained. Hosny et al. (2006) determined that the ultimate carrying capacity of reinforced concrete beams strengthening with hybrid GFRP and CFRP laminates increased by 27.2% compared to the control sample.

Increasing the number of laminate pieces adhered to the beams from 3 to 7 resulted in an increase in flexural strength of approximately 1.1% to 7.8%, except for the CGC-0.50 series. This is an indication that the number of laminate pieces attached to the concrete is not an important parameter in increasing the flexural strength. Because the results showed that the main failure mode was concrete, not laminate pieces, which increased the effectiveness of the reinforcement (Fig. 5).

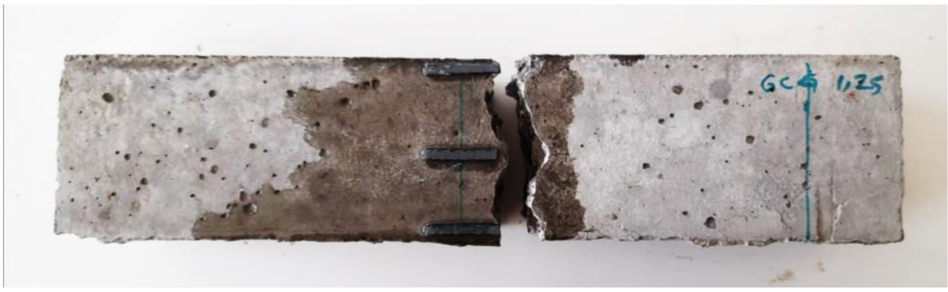

Fig. 5. Fracture mode of concrete reinforced with laminate pieces.

5. Conclusions

This study aims to investigate the effect of different numbers of laminated pieces of carbon-Glass-Carbon and Glass-Carbon-Glass arrays with different ratios of nanoclay in the waste state on the flexural strength of concrete. The main conclusions can be summarized as follows:

- In the Carbon-Glass-Carbon series using triple waste laminate pieces, the highest flexural strength was reported in the CGC-0.75-3 series, which achieved an increase of approximately 55% and 42% compared to the Control and Control-E series.
- The highest flexural strength in the triple array Glass-Carbon-Glass group was obtained in the GCG-0.75 series with 8.84 MPa. In addition, in the triple use of both arrays (CGC-GCG), the highest value in terms of flexural strength of concrete was obtained in the samples using 0.75% nano clay.
- It was determined that the use of laminate pieces with 7 in the CGC-0, CGC-0.50 and CGC-0.75 series increased the flexural strength of concrete by 44.75%, 38.68% and 34.42%, respectively, compared to the Control-E sample.
- It was determined that when the 7-arrays GCG waste laminate pieces used in the reinforcement of concrete

contained 0.50% and 0.75% nanoclay, the flexural strength of the concrete increased by 1.63% and 6.19%, respectively, compared to GCG-0.

- Increasing the number of laminate pieces adhered to concrete beams from 3 to 7 resulted in an increase in the flexural strength of concrete by approximately 1.1% to 7.8%, excluding the CGC-0.50 series. The fact that the numerical increase in the laminate pieces does not cause a significant increase in the flexural strength results is due to the fact that the main failure mode in the samples is in the concrete, not the laminate pieces, which increases the efficiency of the reinforcement.
- Since the laminate parts used in this study were waste, there was no alternative for the dimensions of the parts. In future studies, it is thought that if the laminate pieces used in this study are used in larger sizes, it may be more effective in repair and reinforcement of concrete. In addition, the use of laminate parts in the reinforcement of reinforced concrete samples, which will show more ductile behavior, can provide better observation of the behavior of laminates.

Acknowledgements

None declared.

Funding

The authors received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

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