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Experimental and Finite Element Studies on the Static Behaviour of Concrete Beams Reinforced with Composite Aramid Bars

Phân tích uốn tĩnh dầm bê tông được gia cường bằng thanh composite sợi aramid với phương pháp phần tử hữu hạn và thực nghiệm

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ABSTRACT:

The limitations of concrete structures reinforced with steel are that it is easily destroyed by marine, and island environments. Usage of concrete structures reinforced with composites in load-carrying members of marine structures having concrete frames, and concrete slabs is also gaining popularity recently because of its positive contribution to both energy absorption capacity, concrete strength, and corrosion resistance. This paper presents an experimental and numerical investigation on the static behavior of concrete beams reinforced with composite aramid bars. According, six beams of dimensions (100mm×150mm×1200mm) were cast and tested. The beams are composed of concrete with compressive strength of approximately 40.75MPa and aramid composite bars with tensile strength of approximately 2800 MPa. The main considered variables were the high of beams; and the effect of the diameter of composite aramid bars reinforced on the total capacity of the tested beam. The test and numerical simulation results showed that using composite aramid bars reinforced in the concrete beams has a significant effect in enhancing the increase the flexural strength of the beams. ANSYS finite element software was used to simulate the tests and it was found that there was good conformation between the results of ANSYS simulation and tests. This study showed that the theoretical and experimental results are similar and the error is small, which shows that the numerical simulation method by ANSYS software is accurate.

Keywords: Concrete, beams; experimental; aramid composite; reinforced.

TÓM TẮT:

Kết cấu bê tông cốt thép có nhược điểm là dễ bị phá hủy bởi môi trường biển và hải đảo. Do đó, kết cấu bê tông được gia cường bằng vật liệu composite sử dụng trong các bộ phận của công trình biển như khung và sàn bê tông đang trở nên phổ biến thời gian gần đây. Dạng bê tông này có khả năng hấp thụ năng lượng, tăng cường độ bê tông và chống ăn mòn tốt. Trong bài báo này, các tác giả nghiên cứu thực nghiệm và mô phỏng số uốn tĩnh của dầm bê tông được gia cường bằng thanh composite sợi aramid. Tác giả đã chế tạo và thử nghiệm sáu dầm có kích thước (100mm × 150mm × 1200mm). Dầm được làm bằng bê tông có cường độ nén xấp xỉ 40,75MPa và các thanh composite sợi aramid có độ bền kéo khoảng 2800 MPa. Các đại lượng được đánh giá chính là chiều cao của dầm và ảnh hưởng của đường kính, các thanh aramid được gia cường đến khả năng chịu lực của dầm. Kết quả thử nghiệm và mô phỏng số cho thấy việc sử dụng thanh composite sợi aramid trong dầm bê tông làm tăng cường độ chịu uốn của dầm. Kết quả mô phỏng bằng phần mềm ANSYS và thực nghiệm cho kết quả tương tự nhau và sai số nhỏ, điều này cho thấy phương pháp mô phỏng số bằng phần mềm ANSYS là chính xác.

Từ khoá: Dầm bê tông; thực nghiệm; composite sợi aramid; gia cường.

1. INTRODUCTION

Statically indeterminate elements such as continuous beams are common in structures that might be exposed to harsh weathering and the use of deicing salts. Using composite aramid bars reinforcement in such structures is a viable alternative to traditional steel to overcome corrosion and destroy problems. In general, composite aramid bars reinforced statically indeterminate beams are capable of redistributing bending moments between critical sections. Such distribution gives the structure a favorable ductile behavior and ample warnings before failure. Due to the linear-elastic behavior of composite materials up to failure, the ability of composite aramid bars-reinforced continuous concrete beams to redistribute moments needs to be investigated.

Hoang Phuong Hoa, Nguyen Huynh Minh Trang [1] studied the computational structural design of reinforced concrete composite prestressed standard "Prestressing concrete structures with FRP tendons" ACI 440.4R-04 of the United States. Tran The Truyen et al. [2] studied the response of Glass Fiber Reinforced Polymer (GFRP) reinforced light weight concrete slab used for replacing wooden ties on steel-girder railway bridges. Nguyen Thai Chung et al. [3] analyzed static and dynamic response of piezoelectric laminated composite beams and plates under different types of loads. Mostafa El-Mogy et al. [4] studied behavior of continuous concrete beams reinforced with iber reinforced polymer (FRP) bars subjected to static loads by experimental method. Harith Abdullah ALI [5] used experimental and numerical on continuous reinforced concrete beams strengthened or retrofitted by bonding composite materials analysis under static loads. Arrcording, a study on the flexural performance of reinforced concrete continuous beams with three spans repaired or strengthened by bonding carbon fiber fabric (CFRP) or glass fiber (GFRP). The experimental program consists of two groups: group-1 consists of nine beams and group-2 consists of seven beams, each group including a reference beam. Mostafa El-Mogy et al. [6] analyzed continuous concrete beams reinforced with fibre reinforced polymer bars and stirrups by experimental testing and finite element modeling under static loads. In this study, the experimental results of ten full-scale continuous concrete beams are summarized followed by a finite element parametric study using ANSYS software. Steel, glass fiber reinforced polymer, and carbon fiber reinforced polymer bars were used in different combinations as longitudinal and transverse reinforcement. Min Sun et al. [7] used experimental and finite element method on mechanical property of steel fiber reinforced concrete (SFRC) T-Beam analysis subjected to static loads. Studies have shown that the test results and finite element software simulation both showed that the incorporation of steel fibers in the concrete can increase the integral rigidity and ultimate shear capacity, while partially reducing the propagation of cracks effectively. It was also proved that it is reliable to simulate SFRC T-beam by ANSYS software. Most of the above structures are susceptible to corrosion and destruction when used for marine, island, or saline environments, so the study of concrete structures reinforced with composites in order to overcome the above limitations of steel-reinforced concrete structures is necessary. This paper presents an experimental and numerical investigation on the static behavior of concrete beams reinforced with composite aramid bars. According, three type beams of dimensions (100mm×150mm×1200mm) were cast and tested. The beams are composed of concrete with compressive strength of approximately 40.75MPa and aramid composite bars with tensile strength of approximately 2800 MPa.

2. EXPERIMENTAL STUDY

2.1. Experimental Procedure

2.1.1. Description of Specimens: In this test, three test rectangular beams (R-beams) with 1.2-meter of length were prepared. The parameters of beams are shown in Table 1. 30S aramid bar was used as the three type tension longitudinal reinforcement and stirrups, where the longitudinal reinforcement with 8mm, 10mm, and 12mm diameter, while the width, height and length are 100, 150 and 1200mm, respectively. The description of the experimental set-up and the section size, the composite aramid bars reinforced layout in the beam is shown in Figure 1 [8], [9], [11], [12].

Table 1. Test R-beams parameters

Beam node	Composite aramid bar diameter (mm)	Beam length (mm)
1	8	1200
2	10	1200
3	12	1200

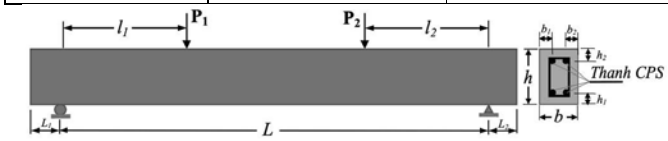


Figure 1. Section size and reinforcement layout

L = 1000, l_1 = 350 (unit: mm)

2.1.2.Materials Properties: In this experiment, the mechanical properties of concrete and 30S composite aramid reinforced bars are shown in Tables 2.

In this test, the mechanical properties of concrete and 30S aramid composite reinforcement bars were determined by the MTS 810 tensile (compression) test system, the results are shown in Table 2.

Figure 2. Testing on MTS 810 system

Table 2. Mechanical properties of concrete and 30S composite aramid reinforced bars

Materials	Properties				
	Young's modulus E_c(GPa)	Density ρ_c(kg/m^3)	Poisson ratio ν_c	Tensile strength (MPa)	Compressive strength (MPa)
Concrete	28.92	2200	0.2	2.78	40,75
Composite aramid 30S	130	1.45	0.25	2800	2800

2.1.3. Measuring devices, generating load: In the test, the method of two-point loading was used by the distributive beam (Fig. 1). The support of the beam was 100 mm far from the beam end [11], [12]. The loading device was a separate type of hydraulic jack that used a high-precision static servo-hydraulic-control system. Gradation loading was acted on the beam, and the holding time was 15 minutes. In the process of loading, the crack occurrence and development should be carefully observed. Displacement gauges were arranged lower face of the beam and the mid-span (Fig. 1). In each loading process, the corresponding load and displacement values were recorded synchronously.

2.2. Experimental Results and Discsusion

The tests were carried out at the laboratory of Le Quy Don Technology University. Some test images are shown in Figure 2, 3. The results show that crack load (P_{cr}), ultimate load (P_u), and mid-Span displacement (W_{max}) corresponding to the ultimate load of these three beams are shown in Table 3. The load-displacement curves of the three beams are shown in Figure 3.

Figure 3. Bending test of concrete beams reinforced with composite aramid bars

Table 3. Summary of bending resistance of beams

Beam node	P_{cr}(KN)	P_u(KN)	W_{max}(mm)
1	236	986	10.8
2	409	1130	8.4
3	560	1326	7.9

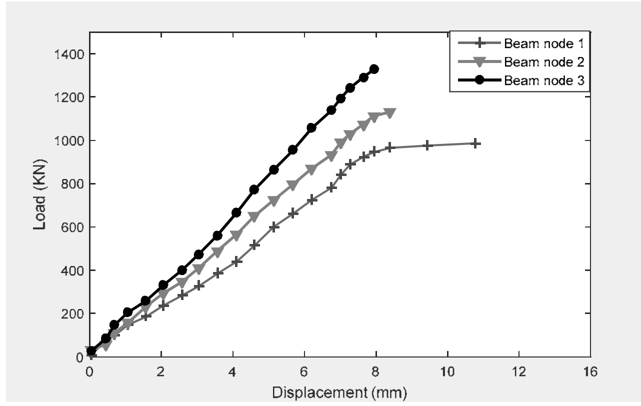


Figure 4. Load-displacement curve of the beams

The crack diagram of each beam is shown in Figure 5.

Figure 5. Crack pattern for the tested beams

3. FINITE ELEMENT FORMULATION

3.1. Element Selection and Finite Element Model

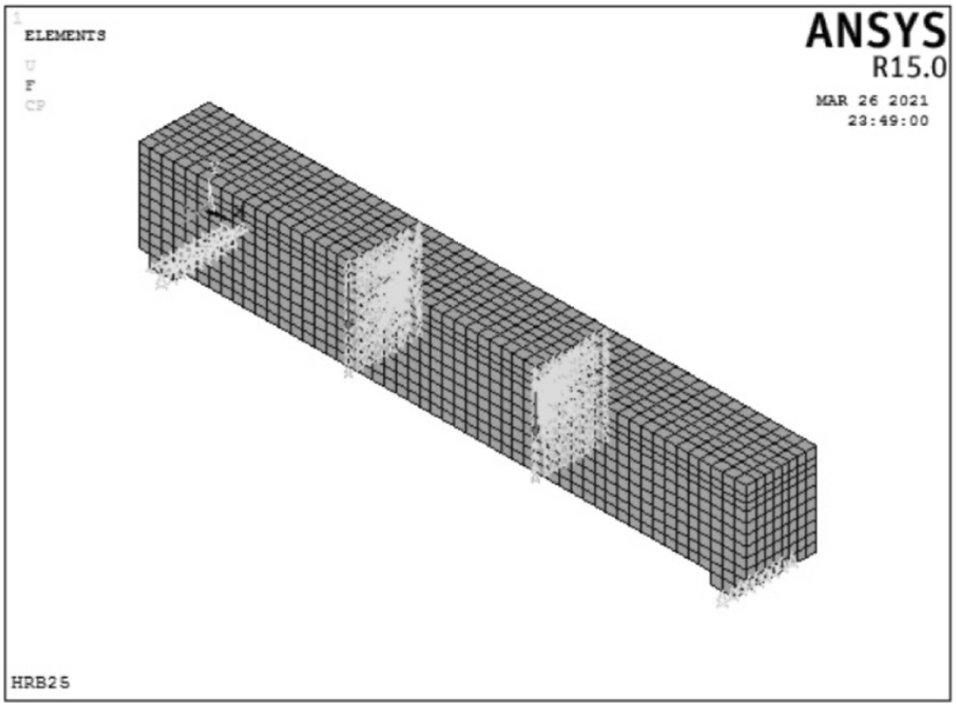
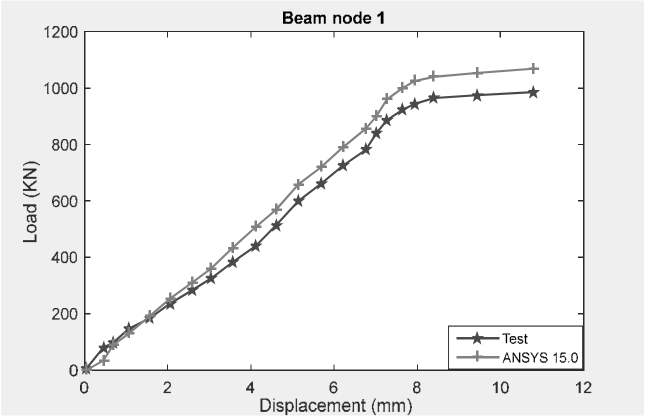
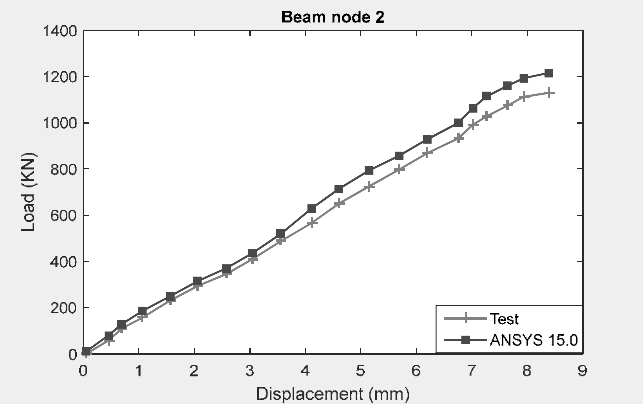


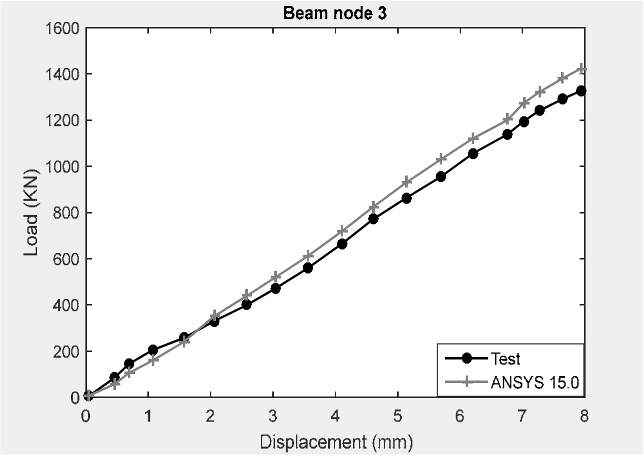
Figure 6. ANSYS software model



a) Beam node 1 comparison diagram



b) Beam node 2 comparison diagram



c) Beam node 3 comparisondiagram

Figure 7. The load - displacement curve of the beam with two methods: finite element and experimental

concrete beams reinforced with composite aramid bars, a separate model was adopted [3], [10]. The concrete was simulated by Solid 65 element and composite aramid bar was simulated by Pipe 59 element. The bond slip between the composite aramid bar surface and concrete was neglected. Normally, in the finite element simulation, the stress concentration was avoided at the support and the loading point by adding an elastic pad. The ANSYS software model is shown in Figure 6.

3.2. Comparative Analyisis of Finite Element Results and Experimental Results

Numerical simulation using ANSYS sorftware, the cracking load and ultimate load of three R-beams by ANSYS simulation and experimental results are shown in Table 4.

Table 4. Finite element simulation and experiments results

Beam node	$P_{cr,cal}$(KN)	$P_{cr,exp}$(KN)	*Error (%)*
1	253	236	*7,2*
2	435	409	*6.3*
3	597	560	*6.6*
Beam node	$P_{u,cal}$(KN)	$P_{u,exp}$(KN)	*Error (%)*
1	1069	986	*8.4*
2	1216	1130	*7.6*
3	1422	1326	*7.2*
Beam node	$W_{max,cal}$(mm)	$W_{max,exp}$(mm)	*Error (%)*
1	10.1	10.8	*6.3*
2	7.9	8.4	*5.4*
3	7.3	7.9	*7.1*

According to the study results, it can be seen that the load-displacement curve of the finite element simulation is basically consistent with that of the test. But the slope of the curve obtained by the finite element simulation is larger than that of the test results. These show that the stiffness of the concrete beams reinforced with composite aramid bars simulated by the finite element is more than that of the test result. The main reason for this situation is the simulation of concrete beam reinforced with composite aramid bars inner was ideal and with no flaws. In addition, due to the manufacturing process of beams in the actual process, the stiffness of the beam simulated by ANSYS is greater than that of test results.

Test results and numerical simulations also show that, when the diameter of the aramid composite bars increases, the crack load and ultimate load also increase, while the mid-span displacement of the beams decreases but not linearly.

With the uniformity of load-displacement relationship curves shown in figure 7 and error between experimental results and numerical simulation results from 6.3% to 8.4% (for crack load and ultimate load), and from 5.4% to 7.1% (for mid-span displacement) as shown in table 4 show that the finite element method described above is suitable.

4. CONCLUSIONS

- The theoretical and experimental results are similar and the error is small, which shows that the numerical simulation method by ANSYS software is accurate.
- The incorporation of composite aramid bars and concrete can improve the integral rigidity and ductility of concrete structures (for example R-beam). In a certain range, the higher the diameter of the composite aramid bar is the higher the higher the beam stiffness.
- The adhesion between the surface of the concrete beam reinforced with composite aramid bars and the concrete reinforced is good, the beam stiffness is about 75% of the stiffness of the reinforced concrete beam of the same size. This shows that the study and application of concrete structures reinforced with aramid composite bars.

Data Availability: The data used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

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