SUSTAINABILITY ASSESSMENT OF HYBRID REINFORCED CONCRETE BEAMS

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1. Introduction

A hybrid reinforced concrete beam contains aramid fibers, and is made using two layers of concrete: normal concrete on the bottom half and high strength concrete on the top. Due to the use of two different materials, a hybrid beam can handle a larger moment than a conventional beam. While the primary purpose of this technology is to prevent sudden failure and provide early warning during disasters, the sustainability of hybrid beams is still unclear. However, the sustainability should be quantified, as the topic is becoming increasingly critical because concrete consumes large amounts of materials and releases environmental degrading substances. This paper investigates how the environmental emissions, cost of materials, and safety measurements interact to portray the sustainability of the hybrid beam.

2. Methodology

2.1. Materials

The constituent materials used in this experiment are: Ordinary Portland Cement (OPC), type C fly ash (FA) containing high calcium oxide, coarse aggregates (G) in saturated surface dry condition with gradation following ASTM C-33, sand (S), aramid fibers (AF) twisted to a length of 30mm, water (W), and super plasticizer chemical admixture (Ad) used to restore the workability lost due to the addition of AF.

2.2. Mix proportions and casting

The mix design is divided into two types of concrete: normal strength concrete and high strength concrete. The mix proportions are in Table 1, where fly ash was used as a replacement for cement. The quantity of aramid fiber added to mixes except the control was 1% of the volume of concrete. To eliminate the interfacial crack between layers during casting, the second layer of concrete was placed while the bottom layer was still in the fresh state, and vibrated carefully. The specimens were covered with burlap and cured up to 28 days.

Table 1: Mix proportion

Name	w/b	Mix proportion (kg/m^3)						
		C	FA	W	S	G	Ad	AF
NSC38	0.47	272.3	117	182	766	1013	0.18	-
AFRC32	0.55	228.9	123	193	766	1013	0.9	1
AFRC38	0.47	272.3	117	182	766	1013	1.1	1
HSC53	0.37	360.2	90	165.8	766	1013	0.7	1
HSC84	0.28	473	0	146.4	766	1013	1.2	1

2.3. Experimental set up

The length of the hybrid beam specimen was 2.1m, with a cross-section of 150mm x 250mm. The reinforcement was 2-20mmΦ rebar at the bottom and 2-12mmΦ at the top, with 9mmΦ stirrups. The beams were load-tested at four loading points, and the moment capacity and deflection were recorded. To observe the strain of concrete around the crushing zone and yielding strain of steel reinforcement, linear variable differential transformers (LVTD) were used.

3. Results

3.1. Mechanical results

The moment-deflection curves for all beams are reflected in Figure 1. Based on this figure, the hybrid beams sustained higher deflection compared to the control, which can be attributed to the presence of aramid fibers, suggesting that AF improved the ductility of the hybrid beams. From the same figure, the moment capacity of hybrid beams also increased relative to the control, except for AFRC32-NSC32. Because of this, failure and sudden collapse of structures may be avoided.

Keywords: aramid fiber, hybrid, beam, moment, deflection, sustainability

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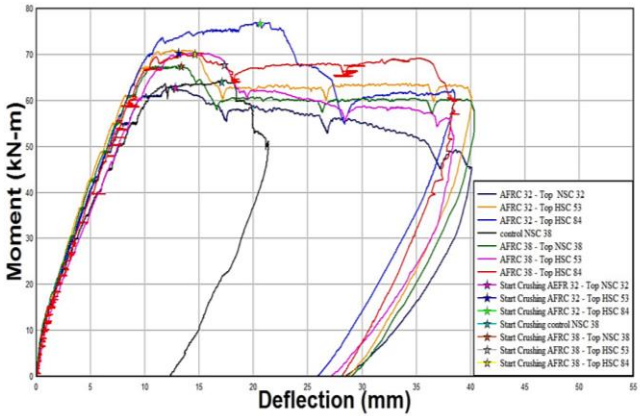

Figure 1: Moment-deflection graph

3.2 Sustainability of hybrid concrete beams

The previous section showed that most of the hybrid beams perform better mechanically than the conventional control beam. To assess their sustainability, two additional indicators were also investigated: cost and carbon dioxide emissions. Together with the social aspect, these environmental and economic aspects have roles to represent the three pillars of sustainability.

The cost and CO_2 were calculated using the inventory data in Table 2. The costs of the beams, representing the economic aspect, were calculated using the amount of materials (except aramid fiber due to lack of data), and including transportation costs (expressed in Thai Baht). Carbon emissions, on the other hand, represent the environmental aspect, and were calculated from material-associated emissions and transportation only. Due to lack of information, other inputs were not considered (e.g., AF, mixing equipment, etc.). To represent the social aspect, the safety was taken as the bending moments at the onset of crushing. The values of the indicators are shown in Table 3.

Table 2: CO_2 emission and costs of materials

Material	CO_2 (kg-CO_2/t)	Cost (Baht/kg)
OPC	1,088	2.4
Fly ash [1]	0	1
Coarse aggregate [2]	2.76	2.25
Fine aggregate [1]	3.92	0.3
Steel reinforcement	315	46.33

The indicators were next normalized relative to the control beam for comparability (Table 4), where values above the control mean more sustainable. The indicators were composited by linear aggregation using equal weights to determine the most sustainable hybrid beam. From the composite values, some hybrid beams are lower than the control beam, implying that using two layers of concrete with different strengths may not necessarily be more sustainable. However, the specimens AFRC32-NSC32 and AFRC38-NSC38 are relatively the most sustainable based on the composite value. This might be due to fly ash higher replacements compared to others, reducing the cost and CO_2 emissions substantially.

Table 3: Generalized value per beam

Name	Cost (Baht)	CO_2 (kg)	Moment at Start crushing (kN-m)
Control 38	1035	39.9	64.4
AFRC32-NSC32	1028	36.2	61
AFRC32-HSC53	1039	41.8	70.6
AFRC32-HSC84	1045	46.3	70.3
AFRC38-NSC38	1035	39.9	67.5
AFRC38-HSC53	1043	43.6	69.4
AFRC38-HSC84	1050	48.2	69.8

Table 4: Normalized value

Name	Economic	Environment	Social	Composite values
Control 38	1.000	1.000	1.000	1.000
AFRC32-NSC32	1.007	1.092	0.947	1.016
AFRC32-HSC53	0.997	0.954	1.096	1.015
AFRC32-HSC84	0.990	0.839	1.092	0.974
AFRC38-NSC38	1.000	1.000	1.048	1.016
AFRC38-HSC53	0.993	0.908	1.077	0.993
AFRC38-HSC84	0.986	0.793	1.084	0.954

4. Conclusions

The moment capacity and ductility of the hybrid beams increased due to the presence of aramid fiber. The mechanical performance, however, does not guarantee sustainability. Additional, using two different concrete strength to make hybrid beams contributes less to sustainability. Analysis based on the combination of cost, CO_2 emissions, and strength pinpoint AFRC32-NSC32 and AFRC38-NSC38 as the most sustainable beams.

References

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