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Article

Strength and Durability Study of Aramid Fibers in Retrofitting of Reinforced Concrete Structure

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Abstract: Fiber reinforced polymer (FRP) is one of the important material used for strengthening and retrofitting of reinforced concrete structures. The commonly used fibers are glass, carbon and aramid fibers. Durability of structures can be extended by selecting appropriate method of strengthening. FRP wrapping is one of the easiest methods for repair, retrofit and maintenance of structural element. Deterioration of structures may be due to moisture content, salt water, or contact with alkali solutions. There is significant effect of permeability, rise in temperature, chemical attack, fatigue action, micro pores on members of structures. Using FRP additional strength can be gained by structural elements.
This paper investigates durability of aramid fiber subjected to acid attack and temperature rise. Concrete cubes are prepared as specimens with double wrapping of aramid fibers. Diluted hydrochloric acid solution is used for immersion of specimen for curing period of 7, 30 and 70 days. In case of fire resistance test, such specimens are kept in hot air oven at a temperature of 200^{0}C at different time intervals. The effect of aramid fiber wrapping on compressive strength and weight loss of specimen is studied.

Keywords: Fiber reinforced polymer; repair; retrofit; durability; aramid fiber; wrapping.

1. Introduction

1.1 Fiber-reinforced polymer (FRP)

Fiber reinforced polymers are extensively used in strengthening and retrofitting of structurally deficient infrastructures. The polymer is typically an epoxy, vinyl-ester or polyester thermosetting plastic, and phenol formaldehyde resins. When two or more materials with different physical and chemical properties are comprises, forming such types of composites. There is insufficient database on FRP materials which creates difficulties for civil engineers and practitioners in using FRP material at regular basis. V. Karbhari *et al.* [1] studied the durability of FRP as internal reinforcement, external strengthening, seismic retrofit, bridge decks, structural profiles, and panels. FRP wrapping is very easy to handle and having rapid speed in installation. These materials are having high strength-to-weight ratio. Proper attention is required for bond between FRP material and concrete surface. Marinella and Giovanni [2] worked on the compressive behavior of clay brick masonry columns reinforced either with Basalt Fiber–Reinforced Cementitious Matrix (BFRCM) or with steel wire collaring. Installation of FRP is one of the easiest retrofitting techniques due to its high speed and less complex nature. It also creates fewer disturbances to the occupants. Compared with steel plates FRP are more durable, no risk of corrosion and highly resistant to aggressive environment as investigated by Nur Hajarul Falahi *et al.* [3]. Due to extensive use of FRP in construction industry their durability becomes important factor for selection of proper material in strengthening purpose. Anandakumar *et al.* [4] studied the durability of basalt

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fiber reinforced polymer (BFRC) for retrofitting of RC piles. BFRC are wrapped around concrete cubes and tested for acid immersion and fire resistance test. Hashim *et al.* [5] considered durability of material at two locations. First thing is the material used itself has to satisfy durability requirement and second is the bond interface between FRP material and concrete surface. Some studies are limited to degradation of interfacial bonding in between CFRP and concrete due to environmental exposure. Gartner *et al*. [6] carried out three point loaded flexural testing of compact specimen which is more simple, easy to interpret and statistically valid. Choi *et al*. [7] worked on durability of CFRP material affected by environmental changes. Same material behaves in different fashion under various environmental conditions. Accordingly relative assessment is done to investigate new technique for finding durability of CFRP material designed for same application. Composites of FRP are made up of endless fibers (carbon, glass, and aramid) inserted in the matrix of thermosetting resins of epoxy, vinyl ester or polyester. The resins bound these fibers together to transfer the load in between. (Frigione *et al.)* [8]

1.2 Aramid Fiber Reinforced Polymer

The aramid fiber originates from aromatic polyamide (aramids) depend on para-phenylene teraphthalamide, which introduces amide group and benzene rings into polyamide molecules together. Due to strong inter-chain bonding and high level of crystallization, modulus and tenacity of these fibers are very high. (Chen and Zhou) [9]. According to Jassal and Ghosh, [10] in aramid fibers 85% of amide linkages are directly attached to two aromatic rings. These fibers are having 5 – 10% more mechanical properties than the synthetic fibers. Such fibers are typically used in composite structures for application in aircraft, marine and automobile, rope for offshore oil rigs and bullet proof vests. Aramid fibers are abrasion resistance under cyclic loading. These are five times stronger than steel and heat resistant. For 1 meter wide strip weight of fiber is 300g/m^2. The tensile strength is in between 2400 to 3600 N/mm^2 with percentage elongation of 2.2% to 4.4%. Tensile modulus is 60 GPa to 120 GPa. Kevlar which is a type of aramid fiber was selected by Granata and Parvin [11] as the FRP material and shell chemical epoxy was taken as adhesive.

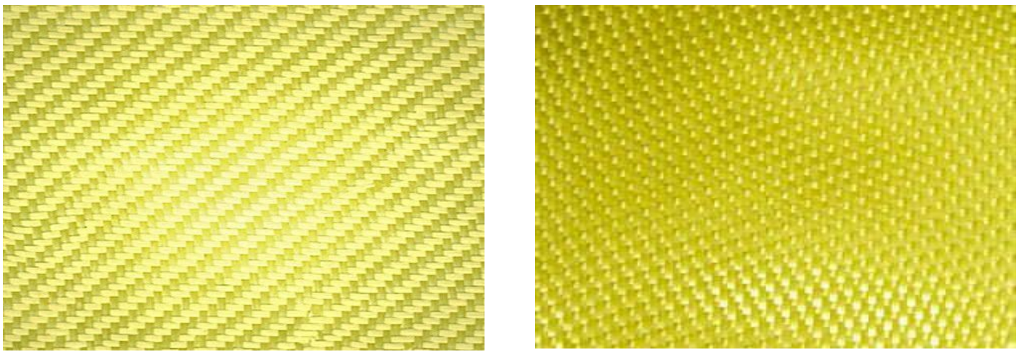

Figure 1. Aramid fiber reinforced polymer.

Pereira and Revilock [12] used aramid fiber named Kevlar fabric of tensile strength 55% greater than E- glass fiber whereas shear strength 180% stronger than E-glass fiber. The bulk density (mass per unit of volume) and linear density (mass per unit of length) of the fabric are 1.44 g/cm^3 and 1.656 x10^3 g/cm^3, respectively. The plain-woven 1414 Aramid fabric, made by Hindoostan Technical Fabrics Limited, Mumbai (India) is used in this study. Figure 1 shows the texture of aramid fiber.

2. Methodology

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A concrete mix design is prepared for M30 grade of concrete. Table 1 shows the design mix proportion for M30 grade of concrete.

Table 1. Proportions of Design Mix

Description	Cement	Fine Aggregate	Coarse Aggregate	Water
Design mix proportions	1	2.14	3.54	0.45
Materials quantities (Kg/m³)	350	749.00	1239	157.50

2.1 Test on Fiber Reinforced Polymer

2.1.1 Acid Resistance test

Total 18 concrete cube specimens are cast with M30 grade of concrete. 9 are conventional concrete cubes called controlled specimens and remaining 9 cubes are doubly wrapped with aramid fiber. These specimens are cured in water for 28 days. After curing these specimens are dried out for 36 hours and their initial weight is taken. After this, these specimens are immersed in 2% HCL diluted acid solution. Casting program of cube is done as per Table 2. The properties of diluted HCL solution are shown in Table 3.

Table 2. 2% HCl diluted solution

Description of Specimen	Specimens immersed in Hcl. Acid solution – Duration		
	0 Day	7 Days	30 Days
Controlled specimens	3	3	3
Doubly wrapped Aramid Fiber specimens	3	3	3

Table 3. Properties of diluted acid solution

Properties of Diluted Hydrochloric Acid (Acid strength 2%)	Value
PH Value	1.54
TDS	54.5PPM

Figure 2. Compressive strength test

These specimens are removed from the water as per the time given in Table 2 and final weight of the specimens is noted. All the specimens are tested for compressive load as per IS 516 (1959). See figure 2 for compressive strength test on specimen. Comparisons are drawn for controlled specimens and doubly wrapped aramid fiber specimens in terms of weight loss and strength loss as shown in Table 4. Comparative charts are drawn in figure 3 and figure 4.

Table 4. Acid resistance test result

Description		After 7 days			After 30 days			After 70 days		
Controlled Specimens	Cube	1	2	3	1	2	3	1	2	3
	Initial Weight in (gm.)	8485	8440	8386	8660	8580	8625	8485	8505	8435
	Present Weight in (gm.)	8470	8429	8405	8639	8555	8638	8453	8467	8460
	Weight loss in (gm.)	15	11	19	21	25	13	35	38	25
	Compressive Strength (MPa)	35.20	35.06	34.94	34.88	34.80	34.23	34.62	34.35	33.86
Doubly wrapped aramid fiber specimens	Initial Weight in (gm.)	8432	8501	8465	8603	8600	8592	8550	8585	8556
	Present Weight in (gm.)	8428	8499	8470	8495	8591	8600	8539	8572	8566
	Weight loss in (gm.)	4	2	5	8	9	8	11	13	10
	Compressive Strength (MPa).	51.11	51.02	50.80	50.31	49.37	49.46	49.28	48.71	48.80

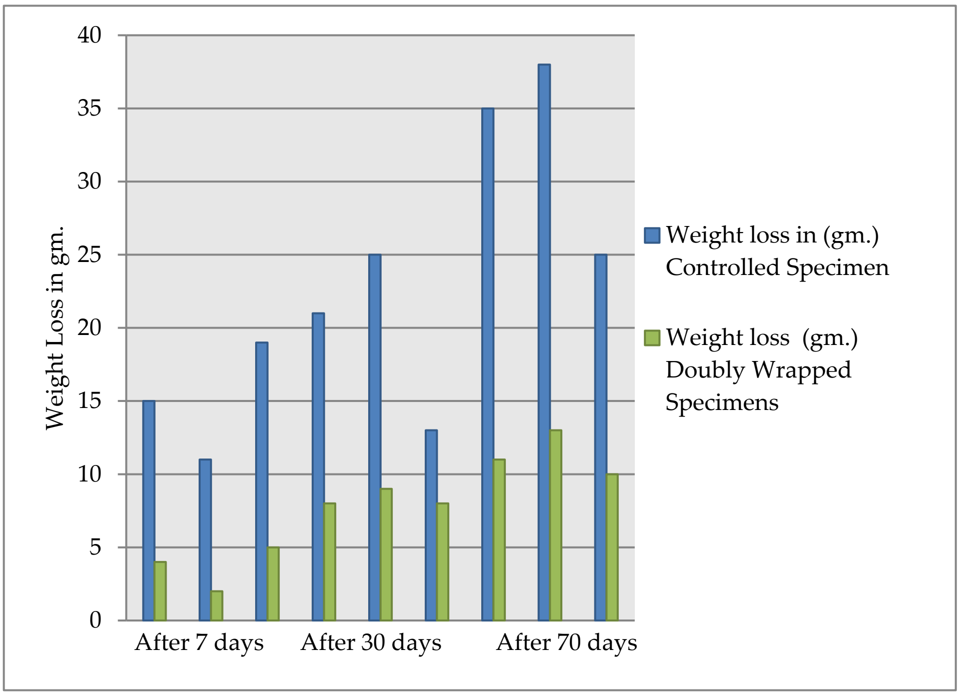

Figure 3. Weight Loss in acid resistance test

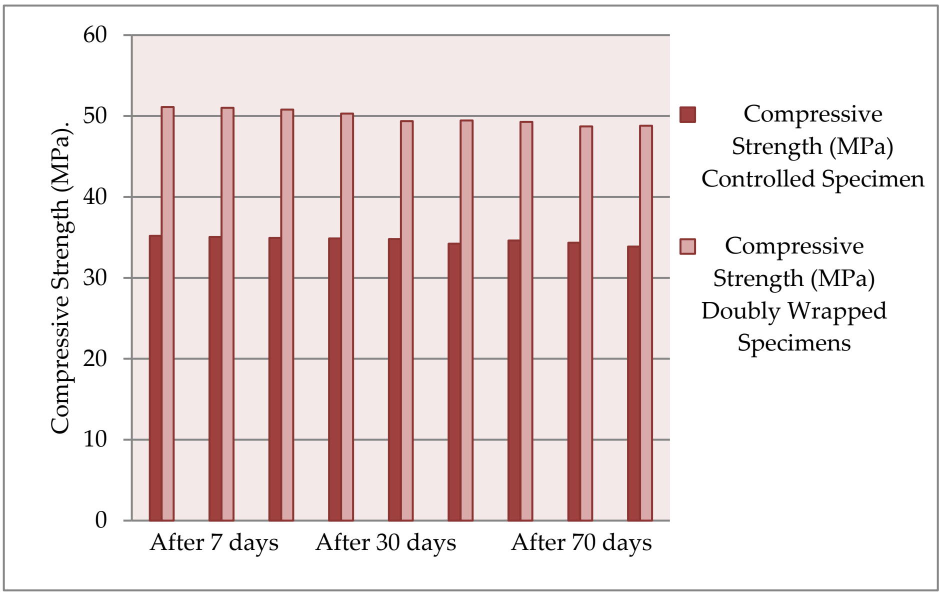

Figure 4. Compressive Strength in acid resistance test.

2.1.2 Fire Resistance test

Concrete cubes are cast and cured for 28 days. In the fire resistant test, first of all initial weight of concrete cube specimen is taken. Then the specimen is kept in the oven at 200°C for a time interval of 1 hour and 2 hour as shown in figure 5. The final weight is taken for each specimen after specific time interval. These specimens are tested for compressive strength. Comparisons are drawn for controlled specimens and aramid fiber double wrapped specimens. Table 5 shows details of fire resistance test after 1 hour. Accordingly comparative charts are drawn for weight loss and compressive strength of each specimen as shown in figure 6 and figure 7. The remaining specimens are kept for 2 hours in oven at a temperature of 200°C. Results are tabulated in Table 6. Based on these results compressive strength and weight loss are compared as per figure 8 and figure 9.

Figure 5. Fire Resistance Test.

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Table 5. Fire resistance test at 200˚C – 1 hr.

Type of Specimen	Initial Weight (gm.)	Final weight after heating (gm.)	Weight Loss (gm.)	Compressive load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
Controlled specimen	8565	8554	11	795	35.33	35.27
	8530	8521	9	780	34.66	
	8495	8482	13	806	35.82	
Aramid fiber double wrapped specimen	8611	8605	6	1194	53.06	53.01
	8609	8601	8	1187	52.75	
	8590	8582	8	1198	53.24	

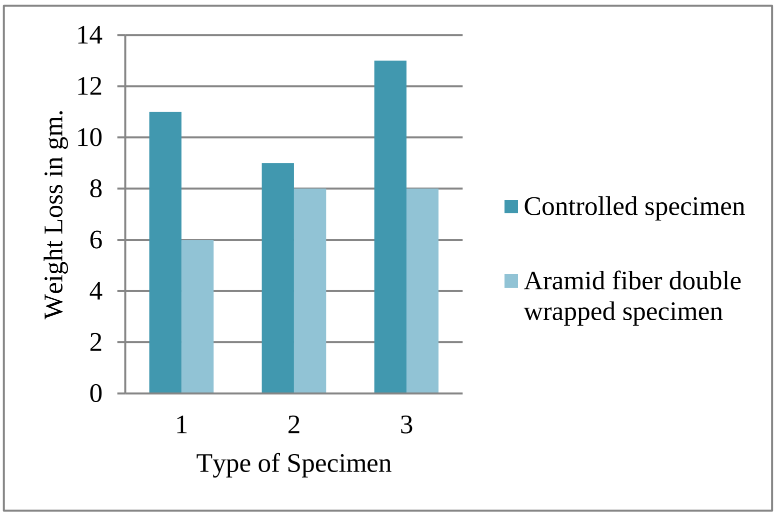

Figure 6. Weight loss at 200˚C – 1 hr.

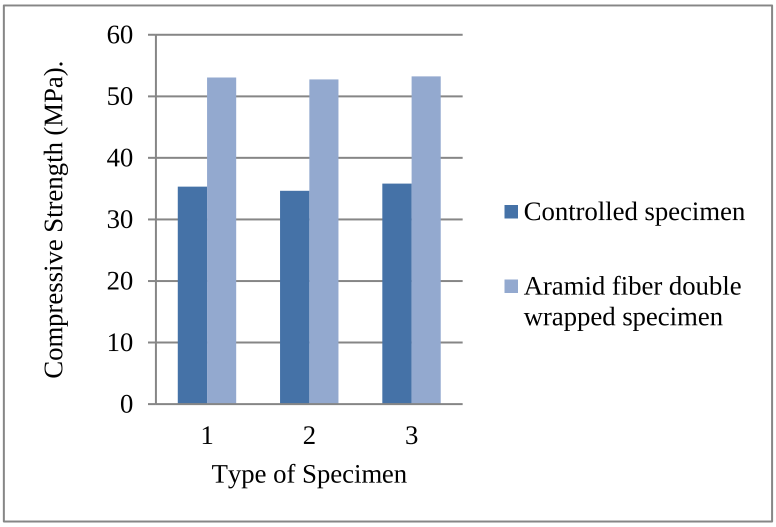

Figure 7. Compressive strength at 200˚C – 1 hr.

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Table 6. Fire resistance test at 200˚C – 2 hrs.

Type of Specimen	Initial Weight (gm.)	Final weight after heating (gm.)	Weight Loss (gm.)	Compressive load (kN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm²)
Controlled specimen	8592	8585	7	802	35.64	35.18
	8553	8539	14	785	34.88	
	8568	4555	13	788	35.02	
Aramid fiber double wrapped specimen	8605	8599	6	1198	53.24	52.84
	8595	8589	6	1189	52.84	
	8587	8580	7	1180	52.44	

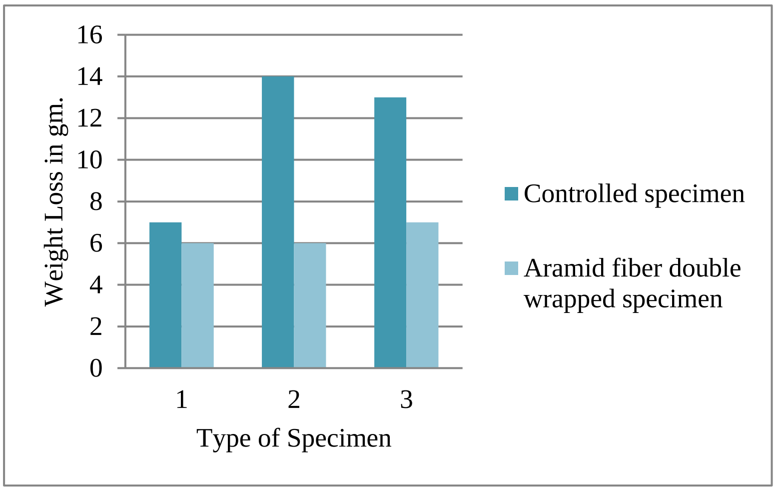

Figure 8. Weight loss at 200˚C – 2 hr.

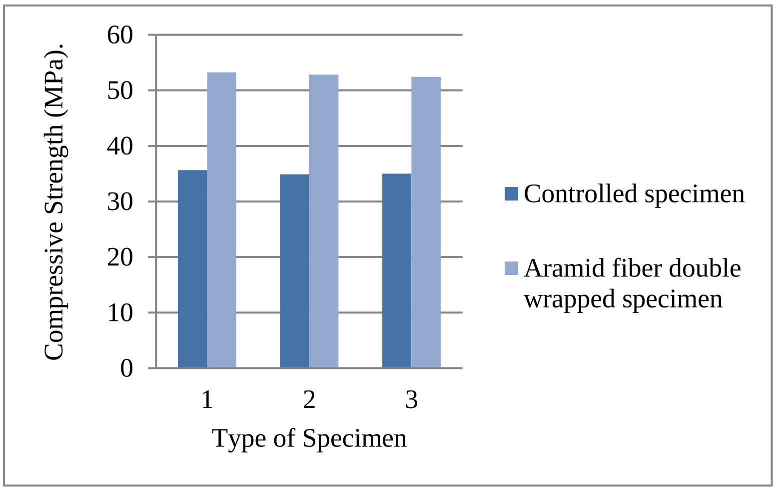

Figure 9. Compressive strength at 200˚C – 1 hr.

3. Discussions

In case of Acid Resistance test, the average weight loss in controlled specimen after 7 days, 30 days and 70 days is 15 gm, 20 gm and 33gm whereas average compressive strength is 35.06 MPa, 34.63 MPa and 34.27 MPa respectively. In case of aramid fiber doubly wrapped specimens the average weight loss is 4 gm, 8 gm and 11 gm and average compressive strength is 50.97 MPa, 49.71 MPa and 48.93 MPa for 7 days, 30 days and 70 days respectively.

When specimens are subjected to Fire Resistance test, after 1 hour of heating average weight loss in controlled specimen is 11 gm and average compressive strength is 35.27 MPa. In doubly wrapped aramid fiber specimen average weight loss is 7 gm whereas average compressive strength is 53.01 MPa. At 2 hours weight loss and compressive strength are is almost same as of 1 hour.

4. Conclusions

From the experimental program following conclusions are drawn

1. In acid resistance test about 26% to 40% weight loss can be reduced by using doubly wrapped aramid fiber.
2. Even after acid attack compressive strength of specimen is increased by 142% even after 70 days by aramid fiber wrapping.
3. In fire resistance test weight loss of specimen can be reduced by 60% using aramid fiber.
4. With the rise in temperature at 200^{o}C for 1 or 2 hour, compressive strength of specimen is increased by 150% when wrapped with aramid fiber.
5. Concrete cubes doubly wrapped with aramid fiber exhibit more compressive strength and less weight loss when subjected to acid attack and thermal effects compared to controlled cube specimens.
6. Aramid fiber can be used as a strengthening material for reinforced concrete elements subjected to compressive load as it enhance durability and increases life of element.

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Conflicts of Interest: "The authors declare no conflict of interest."

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