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RESEARCH ARTICLE

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EFFECT OF PERCENTAGE VOLUME OF BASALT FIBERS ON MECHANICAL PROPERTIES OF CONCRETE AT ELEVATED TEMPERATURE

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ABSTRACT

Concrete has high compressive strength but it is weak in tension as the cement holding the aggregate in place can crack, allowing the structure to fail. Concrete at times need to resist the effects of artificially induced high temperatures near furnaces, in atomic reactors, in pavements subjected to jet engine blast, and in areas exposed to fire. In case of extremely high temperatures, such as launching pads for missiles the concrete may deteriorate but in most instances it is desired to avoid deterioration of the concrete's physical properties as much as possible. Concrete when exposed to elevated temperatures become ductile and cracks. To improve the ductility we add steel bars, natural fibers, and plastic rebar. Natural fibers like basalt fibers can withhold the concrete without cracking at elevated temperatures due to their high elastic modulus, resulting in excellent tensile strength.

The main objective of this research is to evaluate mechanical properties of basalt fiber concrete that are compressive strength and split tensile strength at elevated temperatures. In this study M30 grade of concrete is considered and basalt fibers are added at 0.1, 0.2, 0.3, and 0.4% by volume. The parameters tested are compressive strength and split tensile strength. The specimens of size 100mm X 100mm X 100mm cubes were casted for compression test and size 300mm length X 150mm diameter cylinders were casted for split tensile strength test and are cured for 7 and 28 days. These specimens are exposed to a temperature up to 8000C for every 2000C interval and the temperature is maintained for 3 hours duration in bogie hearth furnacefor sustained temperature condition. The heated specimens are cooled to room temperature and laboratory tests were carried out.

The bond failure and spalling of basalt reinforced concrete is less when compared to conventional concrete.

KEY WORDS: Basalt Reinforced Concrete, Bogie Hearth Furnace, Elevated Temperatures, Spalling, Bond Failure

Introduction

1.1 *General*

Concrete is a composite material which is made of filler and a binder. Typical concrete is a mixture of fine aggregate (sand), coarse aggregate (rock), cement, and water.

When concrete is exposed to high temperatures, the low resistance to crack propagation results in a low fracture toughness and limited resistance to impact and explosive spalling.

When exposed to elevated temperatures the tensile strength in concrete weakens much and failure occurs.

Table 1.1 Behavior of concrete at elevated temperature.

S.No	Temperature (^{0}C)	Behavior of concrete
1	>100	No change in the strength of the concrete.
2	100-200	The split tensile strength and compressive strength of concrete increases.
3	200-400	The split tensile strength and compressive strengthof concrete starts decreases gradually.
4	400-600	The split tensile strength and compressive strength of concrete further decreases.
5	600-800	The split tensile strength and compressive strength of concrete starts decreases suddenly.

The weakness in tension can be overcome by the use of conventional steel bars reinforcement and to some extent by the mixing of a sufficient volume of certain fibers. There are many types of fiber-reinforced concrete: steel fiber, glass fiber, synthetic fiber and natural fiber reinforced concrete.

1.2 *Basalt fibers*

Basalt is well-known as a rock found in virtually every country around the world. Basalt rock is formed after cooling of lava on earth crust.

The first use of fibers in reinforced concrete has been dated in 1870's.

They are environmentally safe and non-toxic, possess high heat stability and insulating characteristics and have an elastic structure.

Basalt fibers are very good in tensile strength and can withstand a temperature of 1,4000C. Basalt fibers are used in textile applications for fire protection, High-Temperature Insulation (HTI), as reinforcement in composite materials.

DETAILED EXPERIMENTAL PROCEDURE

2.1 *Introduction*

The detailed experimental procedure is carried out in various stages such as batching, mixing, placing and compacting, moulding, curing, exposed to elevated temperatures and testing of specimens. Before starting the preparation of specimen the mix design should be prepared.

2.2 *Mix design*

The mix design is done as per IS 10262:2009 and the proportions are tabulated below in Table 2.1.

Table 2.1 Mix design for M30 grade concrete with basalt fibers

Mix Design	Basalt content	Cement (Kg/m3)	FA (Kg/m3)	CA (Kg/m3)	W/C Ratio	Water content (Kg/m3)	Basalt fiber (Kg/m3)
M30	0%	330	725	1242	0.45	148.5	0
	0.10%	330	725	1242	0.45	148.5	2.75
	0.20%	330	725	1242	0.45	148.5	5.5
	0.30%	330	725	1242	0.45	148.5	8.25
	0.40%	330	725	1242	0.45	148.5	11

2.2.1 *Total number of cubes to be cast:*

Cubes are to be cast a total of 150 no's and to be exposed to 27^{0}C to 800^{0}C at an interval of 200^{0}C for 3 hours of duration in bogie hearth furnace.

2.2.2 *Total number of cylinders to be cast:*

Cylinders are to be cast a total of 150 no's and to be exposed to 27^{0}C to 800^{0}C at an interval of 200^{0}C for 3 hours of duration in bogie hearth furnace.

2.3 *Batching*

It is the process of measuring concrete mix ingredients either by volume or by mass and introducing them into the mixture. Traditionally batching is done by volume but in most of the cases batching be done by mass rather than volume. All the materials are taken the weight and carried over to the pan mix.

2.4 *Mixing*

The ingredients are mixed in a pan mix of 50L capacity. The mixing is done in normal mixing approach. First add the cement, fine aggregate and coarse aggregate in the pan mix and mix it for 60 seconds. Then add the required amount of water and mix it for another 60 seconds. If basalt is needed to be added then it must be added to cement, fine aggregate and coarse aggregate.

2.5 *Placing and compacting*

The cast iron moulds are cleaned and oil is applied. Fill the concrete in the moulds in three layers. Compact each layer with not less than 25 strokes per layer using a tamping rod which is steel bar of 16mm diameter and 60cm long, bulletpointed at the lower end. Level the top surface with a trowel as per IS 516-1969.

2.6 *Curing*

The specimens are removed from the moulds after 24 hours from the casting. The specimens are then marked for identification. They are kept in the fresh water for the required curing period.

2.7 *Exposed to elevated temperatures*

Bogie-hearth Furnaces are usually provided with one only sliding type front door for batch loading and unloading. Door support structure is also provided with electromechanical or hydraulic driving system, being supplied by request the door tightening system in order to improve the sealing against the heating chamber frame. Pieces to be heat-treated are charged into the Furnace by means of an electromechanically driven Bogie-hearth, which is used as self-moving Furnace floor.

The heating elements of the furnace are suitably divided into number of heating zones with each zone of having their bank of heater.

The specimens are taken out of curing tank after curing period of 7 and 28 days and dried. The specimens are then exposed to a required temperature in bogie hearth furnace for duration of 3 hours.

Testing of specimens

3.1 *Compression Test on Concrete*

The compressive strength of a material is defined as the value of uniaxial compressive stress reached when the material fails completely. In this investigation, the cube specimens of size 100 mm x 100 mm x 100 mm of all the multi-blended mix concretes are tested in accordance with IS 516 – 1969. The testing was done on an automatic compression testing machine of 200 KN capacities.

In each case the cube was positioned in such a way that the load was applied perpendicularly to the direction of casting with a loading rate of 140 Kg/cm2/min was maintained and it was continued till the specimen fails.

The test was repeated for the three specimens and the average value was taken as the mean strength. Minimum 3 specimens should be selected at each age for each mix. If the strength of any specimen varies by more than 15% of the average strength, results of such specimen should be neglected.

3.2 *Split Tensile strength test on concrete*

The split Tensile strength of the material is defined as the standard test to determine the tensile strength of concrete in an indirect way. This test could be performed in accordance with IS 5816-1999. A standard test cylinder of the concrete specimen (300 mm X 150mm diameter) is placed horizontally between the loading surfaces of Compression Testing Machine.

To allow the uniform distribution of this applied load and to reduce the magnitude of the high compressive stresses near the points of application of this load, strips of plywood are placed between the specimen and loading platens of the testing machine. Concrete cylinders split into two halves along this vertical plane due to indirect tensile stress generated by Poisson's effect.

Results&Discussion

4.1 *Introduction*

The compressive strength and split tensile strength results of M30 grade concrete were discussed in this chapter. To study compressive strength cubes of 100mm X 100mm X 100mm size and for split tensile strength cylinders of 150mm diameter X 300mm length were casted. These specimens were exposed to temperatures of 200°C, 400°C, 600°C & 800°C at 7 days and 28 days of curing. The temperature is maintained for 3 hours in the bogie hearth furnace for sustained temperature condition. These heated specimens were cooled to room temperature and laboratory tests were carried out. The weight loss before and after exposed to elevated temperatures is recorded.

Table 4.1 Variation of Weight loss of concrete with temperature at 7 and 28 days

Temperature (^{0}C)	Basalt Content									
	0%		0.10%		0.20%		0.30%		0.40%	
	7 days (kg)	28 days (kg)	7 days (kg)	28 days (kg)	7 days (kg)	28 days (kg)	7 days (kg)	28 days (kg)	7 days (kg)	28 days (kg)
27	2.565	2.7	2.67	2.71	2.71	2.7	2.73	2.71	2.74	2.693
200	2.538	2.66	2.6	2.65	2.69	2.69	2.65	2.69	2.69	2.68
400	2.425	2.61	2.55	2.63	2.67	2.67	2.64	2.68	2.64	2.645
600	2.42	2.6	2.5	2.61	2.65	2.63	2.63	2.61	2.61	2.617
800	2.405	2.58	2.5	2.6	2.62	2.61	2.58	2.58	2.6	2.592

4.2 *Weight loss*

The results are tabulated and mentioned in Table 4.1. It has been represented in which we can clearly observe increase in temperature results decrease in weight. The weight loss is less in 0.2% basalt fiber content when compared to other mixes of concrete.

Percentage weight loss is calculated and tabulated in Table 4.2 at both 7 and 28 days. The weight loss percentage is high at 800^{0}C. This is because of evaporation of water in the specimen. The concrete with 0.2% basalt fiber at 800^{0}C has less weight loss compared to the other percentage volume of basalt fiber at every temperature.

Table 4.2: % Variation of Weight loss of concrete with temperature at 7 and 28 days

Temperature(^{0}C)	Basalt content									
	0%		0.10%		0.20%		0.30%		0.40%	
	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
27	0	0	0	0	0	0	0	0	0	0
200	1.05	1.78	2.8	2.07	0.7	0.59	3.07	0.81	1.68	0.48
400	5.46	3.55	4.7	2.92	1.66	1.18	3.59	1.11	3.43	1.78
600	5.65	3.92	6.3	3.65	2.47	2.59	3.88	3.61	4.53	2.82
800	6.24	4.4	6.5	4.24	3.58	3.48	5.78	4.87	5.15	3.75

The weight of the concrete specimen decreases gradually in the heating process. The weight loss (in percent) of a cubes specimen after keeping it for 3 hours at a pre-determined temperature, When the testing temperature is in the range of 20 to 200^{0}C, the concrete loses weight quickly, mainly the free water content in the specimen evaporates. When the temperature is in the range of 200 to 400^{0}C the weight is lost slowly as the chemically combined water in the cement motor separates. When the temperature reaches 600^{0}C the calcium hydroxide component produced from the hydration of cement decomposes and dehydrates. When the temperature is at 800^{0}C the magnesium and calcium carbonates in the dolomite and calcite of the aggregates begin to decompose, so the aggregates become unstable and weight loss reach to nearly 7%.

4.3 *Effect of temperature on compressive strength of basalt fiber reinforced concrete at 7 and 28 days*

The below Table 4.3 represents the compressive strength of normal concrete and basalt fiber concrete at 7 and 28 days. In every mix the compressive strength is increased at 200^{0}C and then decreases. The compressive strength at 200^{0}C is increased because of the evaporation of water and decrease in the pore water pressure from the concrete. The compressive strength of the 0% basalt fiber content is higher than the basalt fiber mix concrete at both 7 days and 28 days. This is clearly shown in the graphs below.

Table 4.3 Variation of Compressive strength with temperature at 7 and 28 days

Temperature(^{0}C)	Basalt Content									
	0%		0.10%		0.20%		0.30%		0.40%	
	7 Days MPa	28 Days Mpa	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa
27	35.6	43.3	34.8	41.5	33.4	40.1	31.9	38.5	30.3	38.3
200	37.3	43.5	35.7	42.8	33.8	40.7	32.9	39.4	32.4	39.1
400	34.7	38.5	31.6	38	30.6	36.6	29.5	36.1	26.8	34
600	31	35.3	28.9	35.1	27.7	34.8	25.8	33	22.7	31
800	18.6	20.3	17.3	19.1	15.8	17.4	13.4	15.5	11.7	13.8

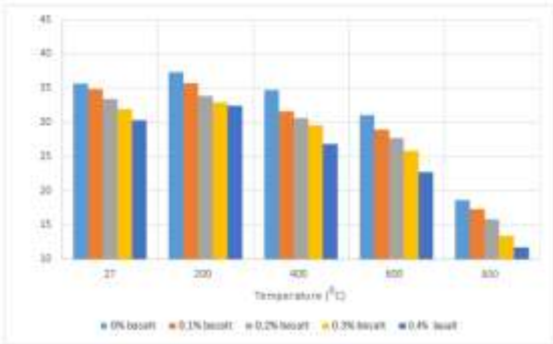

Fig 4.1: Compressive strength versus temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (7 days)

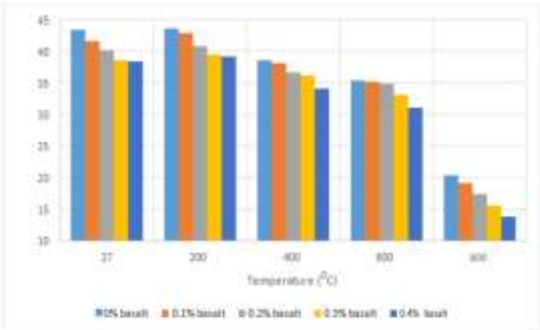

Fig 4.2: Compressive strength versus temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (28 days)

4.4 *Effect of temperature on split tensile strength of basalt fiber reinforced concrete at 7 and 28 days*

The below Table 4.4 shows split tensile strength of normal concrete and basalt fiber mix concrete at 7 and 28 days. The table clearly shows that the strength increases till 200^{0}C and decreases in every mix. The highest tensile strength is obtained at 0.2% basalt fiber mix concrete at both 7 and 28 days at 200^{0}C temperature. The below results are clearly plotted on the graph and are mentioned below.

Table 4.4 Variation of Split tensile strength with temperature at 7 and 28 days

Temperature(^{0}C)	Basalt Content									
	0%		0.10%		0.20%		0.30%		0.40%	
	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa	7 Days Mpa	28 Days Mpa
27	3.3	3.5	2.6	3.1	3.35	3.57	2.77	2.97	3.18	3.2

200	3.45	3.55	3.17	3.27	3.54	3.64	3.14	3.14	3.23	3.26
400	3.28	3.37	2.54	3.03	3.3	3.49	2.65	2.91	2.96	2.87
600	2.31	2.61	2.05	2.25	2.45	2.75	2.11	2.31	2.1	2.2
800	1.2	1.31	1.11	1.16	1.27	1.39	1.09	1.1	1.13	1.27

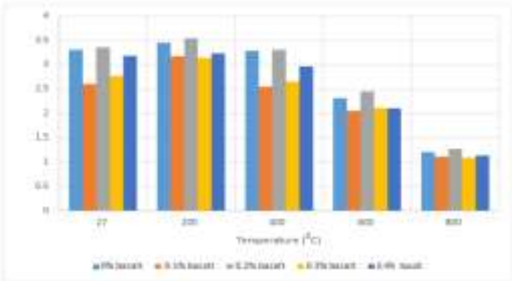

Fig. 4.3: Split tensile strength versus temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (7 days)

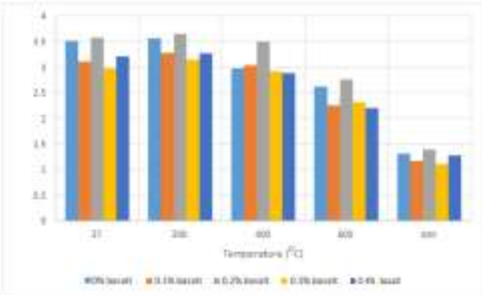

Fig. 4.4 Split tensile strength versus temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (28 days)

4.5 Effect of temperature on percentage residual compressive strength of basalt fiber reinforced concrete at 7 and 28 days

Residual strength is the strength that remains in a concrete after exposed to elevated temperature.

Table 4.5 Percentage residual compressive strength at 7 and 28 days

Temperature(^{0}C)	Basalt content									
	0%		0.10%		0.20%		0.30%		0.40%	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
27	100	100	100	100	100	100	100	100	100	100
200	105	100	103	100	101	102	103	102	107	102
400	97.4	88.9	90.8	91.6	91.6	91.3	92.5	93.8	88.5	88.8
600	87.1	81.5	83.1	84.6	82.9	86.8	80.9	85.7	74.9	80.9
800	52.3	46.9	49.7	46	47.3	43.9	42	40.3	38.6	36

It is clear that the compressive strength of concrete decreases at elevated temperature with all basalt fiber content except around 200°C where there is a considerable increase in the compressive strength is observed. This is due to the evaporation of the free water content which accelerates the hydration and hence increases the compressive strength to 200°C. For temperatures higher than 200°C, the compressive Strength concrete starts to decrease. This decrease is attributed to the fact that chemically-bound water starts to disintegrate and evaporate at this stage. The reason for the decrease in the compressive strength when fibers are used is the poor interface of basalt fiber with cement matrix as well as an increase in porosity due to the addition of basalt fibers in cement paste.

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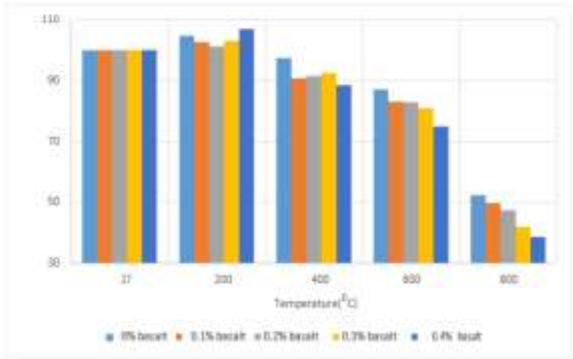

Fig.4.5: Variation of % residual compressive strength with temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (7 days)

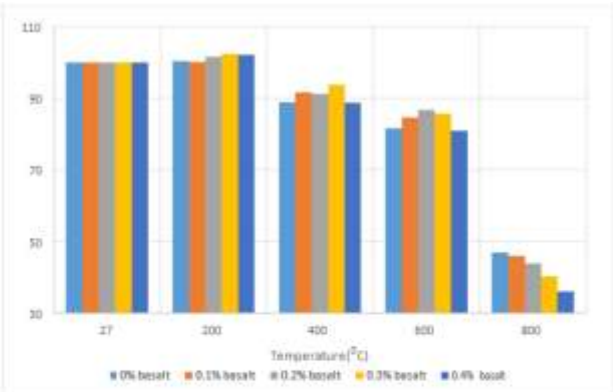

Fig. 4.6: Variation of % residual compressive strength with temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (28 days)

4.6 *Effect of temperature on percentage residual split tensile strength of basalt fiber reinforced concrete at 7 and 28 days*

Table 4.6 Percentage residual split tensile strength at 7 and 28 days

Temperature(^{0}C)	Basalt content									
	0%		0.10%		0.20%		0.30%		0.40%	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
27	100	100	100	100	100	100	100	100	100	100
200	104.5	101	122	105	106	102	113	106	102	102
400	99.39	96.3	97.7	97.7	98.5	97.8	98.5	98	93.1	89.7
600	70	74.6	78.9	64.3	73.1	78.6	73.1	66	66	62.9
800	36.36	37.4	42.7	33.1	37.9	39.7	39.4	31.4	35.5	36.3

Tensile strength is increased up to 200^{0}C due to basalt fiber interlocking mechanism that helps to create a high bond between filaments and concrete and promotes better load resistance between the filaments. At temperature 400^{0}C the tensile strength, performance is dropped due to thermal decomposition and dehydration process of the concerted. At 600^{0}C the basalt fiber becomes brittle and results in a further loss of the strength. At 800^{0}C the concrete deteriorates and micro cracks develop under high intense stress causes low tensile strength.

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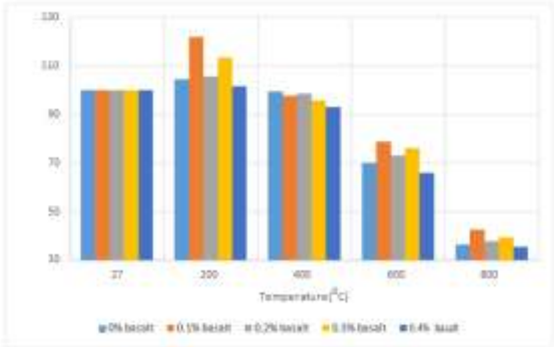

Fig. 4.7: Variation of % residual split tensile strength with temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (7 days)

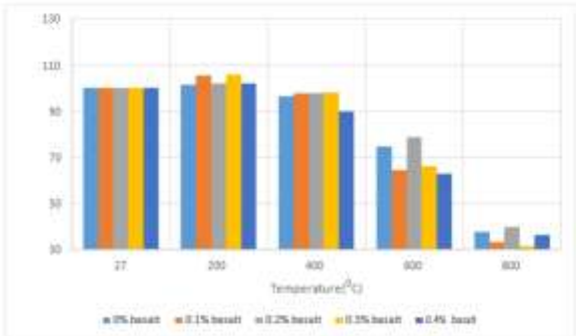

Fig. 4.8: Variation of % residual split tensile strength with temperature for plain concrete and concrete with 0.1, 0.2, 0.3 and 0.4% basalt fibers (28 days)

4.7 *Colour change of concrete with respect to temperature*

Concrete at 0^0C and 200^0C doesn't have any colour change. The colour change will be clearly observed at 400^0C, 600^0C and 800^0C. Concrete changes to light grey at 400^0C and 600^0C. At 800^0C the specimens are pink when heated and when cooled they are of yellowish grey colour.

4.8 Bond failure

Bond failure between the aggregates occurs mostly when it is exposed to elevated temperatures. It is observed mostly at 800°C for both normal and basalt mix concrete. Aggregate with basalt mix have good bonding than without basalt mix concrete.

Conclusions

1. Basalt fibers, when used in concrete, increases tensile strength and resists cracks and bond failure.
2. Split tensile strength is maximum at 0.2% basalt fiber content.so the optimum basalt fiber content is 0.2%.
3. Compressive strength and split tensile strength for basalt mix and conventional concrete of M30 grade increases up to 200°C due to evaporation of free moisture inside the concrete.
4. The weight loss is less for the concrete containing 0.2% basalt fiber than the other mixes.
5. Basalt fibers in concrete reduce the compressive strength when compared to the conventional concrete.
6. The use of basalt fibers is good for obtaining tensile strength than compressive strength.

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