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# Investigaton Of Durability Properties Of Concrete Pipes Incorporating Blast Furnace Slag And Ground Basaltic Pumice As Fine Aggregates

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## ABSTRACT

In this study, the effects of the use of blast furnace slag, ground basaltic pumice and blast furnace slag + ground basaltic pumice as mineral admixtures on durability of concrete pipes were investigated. Blast furnace slag, ground basaltic pumice, and equal amount of blast furnace slag and ground basaltic pumice were used in 5, 10, and 15 % by weight in place of fine aggregate in mixes. Durability of concrete pipes has been tested according to the standard procedures (TS 821, EN 1916). Sulfate resistance and permeability of reference specimen and specimen with admixtures were investigated. It was observed that the ultimate load of specimens depends on type and percentage of admixtures. The maximum ultimate load was obtained in concrete specimens containing 5% blast furnace slag and 5% ground basaltic pumice, which was 20% larger than that of the reference concrete specimens. Furthermore, concrete specimens with 10% ground basaltic pumice were found to have highest sulfate resistance.

## INTRODUCTION

Concrete, which has a wide area of usage in construction world, is a basic construction material that requires attention and diligence at every stage from production to implementation [1]. Concrete has an important place among the materials that form the basis of modern societies. In our environment, buildings, roads, bridges, dams, power plants, retaining walls, water tanks, ports, airports etc. are made up with concrete. Compared to other building materials, concrete is a widely used construction material because it can take any shape made up by formwork and it is economical and durable, requires less energy in production, can be produced at anywhere.

Concrete pipes are frequently used in sewerage and storm water system, underground and over ground irrigation facilities, water transmission lines, water tanks, water towers, pumping lines, pumping stations and water structures such as tunnels. These concrete pipes are exposed to various harmful effects during the service life.

The factors leading to deterioration of the concrete pipes might be originated from physical, chemical, mechanical or biological effects. Impact, wear and erosion are some of the damages that occur mechanically. Chemical effects might occur due to harmful substances leaking into the concrete or materials used in concrete production as well. Common chemical effects are alkali-silica reaction, sulfate attack, carbonation, and corrosion, acid and salt. The physical causes of the deterioration are freeze-thaw, solvent salts, and high temperatures and so on [2]. Studies have been made and continue to have more durable concrete pipes to aforementioned harmful effects. After the addition of steel fiber in concrete, it shows more energy absorption capacity, high impact resistance, high bending strength and fatigue resistance [3]. It is also seen in the experiments [4] that time from the first crack to the ultimate load was increased and showing brittle behaviour was prevented by using steel fiber. In another study, various amounts of glass fibers were used during the manufacture of concrete pipe and as a result, ultimate load values higher than the values given in standards were obtained. Moreover, significant increase in the strength was observed for concrete pipes stayed under the ground for a long time [5]. Permeability adversely affects all the durability characteristics of concrete. Therefore, in recent years, durability has gained more importance in the design of concrete. Mineral admixtures are commonly used in producing more durable concrete.

In this study, the contribution of sand-sized blast furnace slag, and basaltic pumice to the ultimate strength, sulfate resistance and permeability properties of concrete pipes were examined.

## MATERIALS

### *Pumice*

Pumice (P) that occurred as a result of volcanic activities is a porous and lightweight material. Our country has extensive deposits of pumice. Vast majority of Pumice reserves are in East and Central Anatolia regions, especially in cities of Bitlis, Van, Kayseri, Nevsehir and Agri. Besides these reserves, there are also some reserves in the Aegean and Mediterranean regions [14]. Due to sudden release of gases in the structure of pumice during the formation of pumice and sudden cool down, pumice contains numerous pores from macro to micro scale [15]. Since pores are generally detached from each other, pumice is a light material, can float in the water for a long time and has low permeability and high insulation characteristics. Silica content up to 75% can be found in chemical composition of pumice. $SiO_2$ ratio contained in the rock gives rocks abrasive property. $Al_2O_3$ composition leads pumice become heat and fire resistant. Pumice deposits in Turkey are concentrated in Nevsehir, Isparta, Mugla, Kayseri, Ankara, Van, Ağrı and Kars regions. In the study, pumice from Tuysuz, Osmaniye region was used and its chemical composition is given in Table 1.

### *Granulated Blast Furnace Slag*

Granulated blast furnace slag (S), which is containing a large amount of silica and alumina and has amorphous structure, shows pozzolanic properties when it is ground to very fine-grain size [16]. There are various uses of ground granulated blast furnace slag as binding material. It can be used as mineral admixture in concrete in production. Factors like flexibility in preparation of concrete mixtures make it advantageous to grind granulated blast furnace slag separately when to use it as concrete admixture. [17]. In Turkey, the use of slag, which is separately ground, as concrete admixtures has also increased in recent years [18]. The features such as savings in cement, workability, low hydration heat, impermeability and resistance to external factors can be included among the positive effects of pozzolans as additives [16]. Granulated blast furnace slag used in this study (S) was supplied from Iskenderun Iron and Steel Factory and its chemical content are given in Table 1.

Table 1. Chemical composition of Pumice and GBFS

| Components (%) | Pumice | YFC |
|---|---|---|
| $SiO_2$ | 41.41 | 37.89 |
| $Al_2O_3$ | 12.97 | 10.29 |
| $Fe_2O_3$ | 11.41 | 2.95 |

| | | |
|---|---|---|
| CaO | 13.73 | 35.86 |
| MgO | 7.76 | 7.38 |
| $Na_2O + K_2O$ | 5.4 | 1.15 |
| Loss on Ignition | 7.32 | 4.48 |

***Cement***

In this study, CEM I 42,5 type cement was used and its physical and chemical characteristics are given in Table 2.

Table 2. Chemical composition of CEM I 42.5 type Cement

| Components | % |
|---|---|
| $SiO_2$ | 18.85 |
| $Al_2O_3$ | 4.80 |
| $Fe_2O_3$ | 2.40 |
| CaO | 62.80 |
| MgO | 2.50 |
| $Na_2O + K_2O$ | 1.14 |
| $SO_3$ | 3.69 |
| Loss on Ignition | 3.5 |
| Specific Weight (kg/cm$^3$) | 3.12 |
| Specific Surface (cm$^2$/g) | 3250 |
| Remaining on 200 μ sieve (%) | 0 |
| Remaining on 90 μ sieve (%) | 2.5 |

***Aggregate***

Aggregate from Ceyhan River were used in this study.

**EXPERIMENTS**

***Preperation of Mixtures***

Pumice and blast furnace slag were used in substitution of sand of size less than 0.5 mm in preparation of mixtures for concrete pipe specimens. The mixing ratios for each specimen and specimen abbreviations were given in Table 3 and Table 4, respectively.

Table 3. Concrete Mixture Ratios (kg)

| Materials | R | S5 | S10 | S15 | P5 | P10 | P15 | PS5 | PS10 | PS15 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cement | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 | 46 |
| 0-5 Sand | 173 | 155 | 145 | 131 | 159 | 145 | 131 | 155 | 145 | 131 |
| 5-10 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| GBFS | - | 14 | 28 | 42 | - | - | - | 7 | 14 | 21 |
| Pumice | - | - | - | - | 14 | 28 | 42 | 7 | 14 | 21 |
| Total | 273 | 273 | 273 | 273 | 273 | 273 | 273 | 273 | 273 | 273 |

Table 4. Specimen Labels

| Specimens | Meaning |
|---|---|
| R | Reference Specimen |
| S5 | GBFS was substituted for 5% of 0-5mm sand |
| S10 | GBFS was substituted for 10% of 0-5mm sand |
| S15 | GBFS was substituted for 15% of 0-5mm sand |
| P5 | Pumice was substituted for 5% of 0-5mm sand |
| P10 | Pumice was substituted for 10% of 0-5mm sand |
| P15 | Pumice was substituted for 15% of 0-5mm sand |
| PS5 | GBFS and Pumice were substituted for 2.5% of 0-5mm sand, respectively |
| PS10 | GBFS and Pumice were substituted for 5% of 0-5mm sand, respectively |
| PS15 | GBFS and Pumice were substituted for 7.5% of 0-5mm sand, respectively |

***Production Concrete Pipes***

Concrete mixtures given in Table 4 were prepared and molded with the help of machine, which can produce concrete pipes from Ø150 mm up to Ø600 mm in diameter and 1500 mm in length. Production of reinforced concrete pipe with nominal diameter of 500 mm or more is difficult, especially in terms of craftsmanship. In these large reinforced concrete pipes, bending of the reinforcement, welding of joints and placement of reinforcement are very difficult, take longer time and so increases labour costs [19]. In Concrete pipe manufacturing process, inner molds were moved up and outer molds moved down to ground level on two column profiles of 150x200x10 mm with the help of hydraulic power. Once inner and outer molds were locked, the concrete mixture from the bunker with a height of 1.5 m fills the molds with the help of a hydromotor. During the filling, special vibrators placed in inner mold were used to set concrete homogeneously. The mortar was feed to molds with the help of a belt and a hydraulic piston. After filling of mortar into the molds, the belt pulled under bunker with volume of $1m^3$. After completion of this process, the pipe rings were molded. Then, outer molds were moved up and inner molds were moved down. After the completion of this process, the concrete pipes were removed from the machine by attaching fiber headings to prevent any damage on fresh concrete (Figure 1). Then, they were moved to drying yard by hydraulic transporter and then move to cure pool. The samples were kept for a period of 7 and 28 days.in cure pool.

Figure 1. Specimens out of concrete pipe machine

***Ultimate Load Capacity of Concrete Pipes***

Ultimate load test was applied along the entire length. Width of the supports and the distance between the supports were adjusted according to TS 821 EN 1916 [20]. A layer of plaster strip of 2-3 cm thick was applied along the pipe to spread the load uniformly on the concrete. When the plaster gets hardened, compressive load was applied. Speed of loading was adjusted to be in between 7.5 kN/m-30 kN / m according to TS 821. Loading continues until the failure occurs as shown in Figure 2. The ultimate load capacity of concrete pipe was calculated according to effective length of pipe. The resulting ultimate load should not be less than the value given in TS 821 EN 1916.

Figure 2. Determination of Ultimate Load Capacity

***Sulphate Resistance***

In this study, compressive strength of cube specimens with dimensions of 10x10x10 cm, which were prepared by the substitution of slag, pumice and slag + pumice in place of 5, 10 and 15 % of 0.5mm-sized fine aggregate by weight were determined after the specimens were kept in 5% $Na_2SO_4$ sulfate solution. Specimens were kept in water for 28 days for cure and then specimens were kept in oven at 105º C for 24 hours. After the specimens were dried, they were weighed with precision scale. Then the specimens were placed into 5% $Na_2SO_4$ solution and kept there for 180 days. The specimens were removed from 5% $Na_2SO_4$ solution after 180 days and then the compressive strength and mass losses of the specimens were determined.

***Permeability***

Generally, the durability of concrete structures under different conditions is especially related with permeability of the concrete [10]. Permeability coefficient of the concrete was determined according to TS EN 3455. In this study, the amount of water passing through the cylindrical specimens of 7 and 28-day was measured to determine the permeability coefficient of the concrete. Permeability measuring device and test samples are shown in Figure 3. Cylindrical test samples were prepared 15cm in diameter, 30 cm in height with a hole of 20 mm in diameter passing through the centre of the cylindrical samples. 3 test specimens were prepared for each mixture and all specimens were kept in cure tank for 60 days. During permeability test, top and bottom surface of the test specimens were covered with paraffin to make them impervious to water. Water pressure on test specimens was increased by 1 kgf/cm$^2$ until 10 atmospheric pressure was achieved and then it was kept constant throughout the permeability test. Two readings per day were taken from the device. This procedure continued for 7 days. The results were obtained according to penetration depth of the water into the concrete.

**RESULTS AND CONCLUSION**

***Properties of Concrete Mortars***

Slump values showed that concrete mortars had plastic consistency. There was a decrease about 2-3% in slump values of concrete mortars prepared with pumice, blast furnace slag and pumice + blast furnace slag. So, concrete workability was slightly decreased especially with the addition of pumice. The reason for this can be explained by the amorphous nature of the pumice. Because of the high amount of pores in pumice structure, pumice reduces workability by keeping some portion of mixing water in these pores. However, water in these pores does curing effect on concrete and it meets the needs of long-term cure. This shows that tubes were cured internally for a long time. Unit weight values of concrete specimens with pumice were lower compared to other specimens. This could be explained by lower unit weight of pumice. In fact, this is considered as an advantage in terms of ease of transportation of the concrete pipes. Addition of pumice to concrete caused reduction in weight of concrete pipes. This situation can provide convenience of obtaining lightweight concrete elements.

***Ultimate Load Capacity***

Ultimate load tests were performed according to TS 821 EN 1916 and obtained values are shown in Fig. 3.

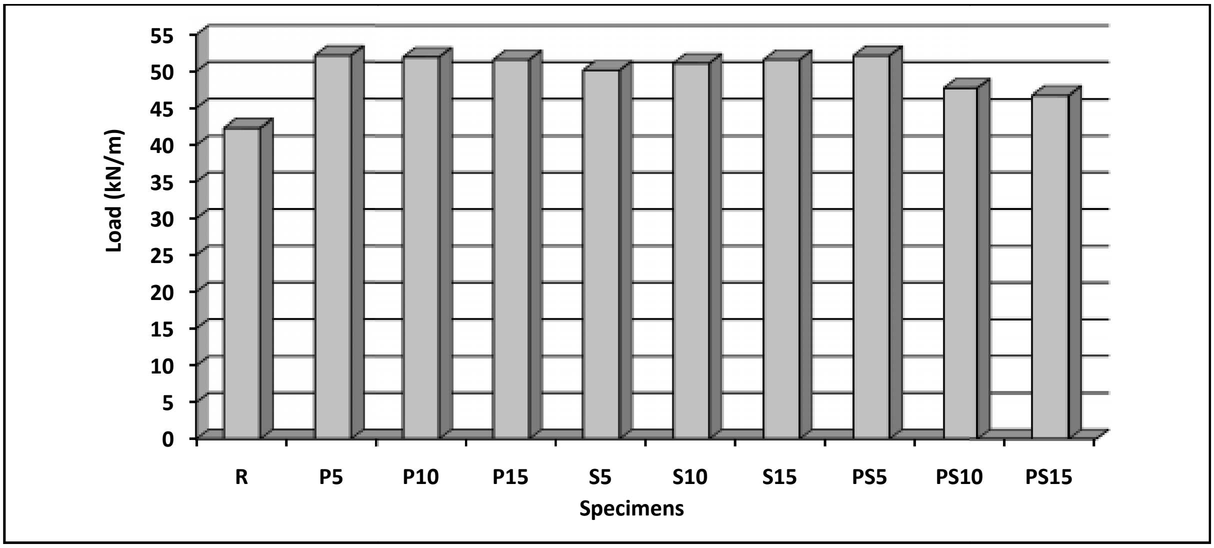


Figure 3. Ultimate load of specimens

In general, the highest load values were obtained from the specimens with addition of pumice as fine aggregate. The lowest load values were obtained from the specimens with addition of both pumice and blast furnace slag as fine aggregate. Ultimate load values of specimens with pumice, blast furnace slag and blast furnace slag + pumice were higher than ultimate load value of specimens without any additives (reference mixture). Highest ultimate load value was obtained from specimens P5 and PS5. Average ultimate load values of both specimens were equal to 52.25 kN/m. The lowest ultimate load value was found in the reference specimen and was equal to 42.29 kN/m. According to these results, it was observed that optimum amount of pumice addition as fine aggregate was 5%. While this rate of pumice addition showed a positive effect on strength, higher amount of pumice addition shows slightly reduction in strength of concrete pipes due to the decrease in the amount fine aggregate.

***Compressive Strength of Concrete Specimens***

Compressive strength of the specimens, which were kept in cure pool for 28 and 180 days, were investigated. Compressive strength of the specimens is shown in Table 5.

Table 5. Compressive strength of the specimens (MPa)

| Specimens | 28 day | 180 day |
|---|---|---|
| P5 | 44,6 | 55,6 |
| P10 | 42,9 | 55,4 |
| P15 | 40,5 | 54,9 |
| S5 | 49,2 | 60,9 |
| S10 | 52,7 | 63,2 |
| S15 | 56,1 | 66,3 |
| PS5 | 47,1 | 58,2 |
| PS10 | 46,6 | 57,5 |
| PS15 | 46,3 | 56,9 |
| Reference | 46,5 | 57,2 |

The maximum 28-day compressive strength values were obtained from S specimens. Compressive strength values of these specimens were between 49-56 MPa. Values of this group of specimens were about 20% greater than that of the reference specimen. However, compressive strength of specimens with pumice was about 13% lower than that of the reference specimen. On the other hand, compressive strength of specimens with pumice and blast furnace slag was equal to reference specimen.

The maximum 180-day compressive strength values were obtained from S specimens. The values were between 60-66 MPa. Compressive strength of this group of specimens was about 18% greater than that of the reference specimen. However, the value of specimens with pumice was about 13% lower than that of the reference specimen. On the other hand, compressive strength of specimens with pumice and blast furnace slag was almost equal to compressive strength of reference specimen.

***Mass loss of samples immersed in sulphate***

Mass loss of specimens immersed in 5% $Na_2SO_4$ solution for 180 days shown in Fig. 4.

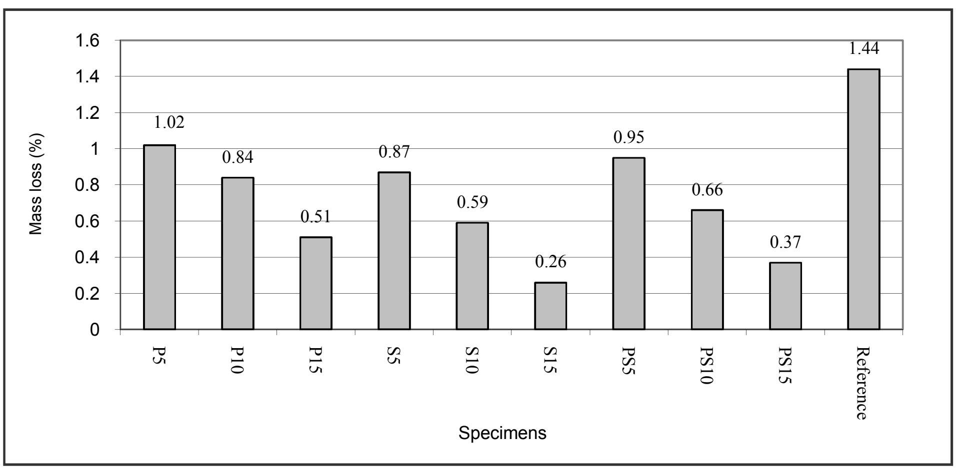


Figure 4. Mass Loss of Specimens immersed in Sulphate Solution

In this short-term sulphate resistance test, the maximum mass loss was observed in reference specimens and the minimum weight loss was observed in S15 specimens. In general, specimen with additives shows less mass loss. This was a result of pozzolanic materials being resistant to sulfates. It was obvious that when concrete pipes exposed to aggressive environmental conditions, concrete pipes produced with pozzolanic additives shows better performance than performance of the concrete pipes without any pozzolanic additives.

***Compressive strength of specimens immersed in sulphate***

Compressive strength of specimens immersed in 5% $Na_2SO_4$ solution for 180 days are shown in Fig. 5.

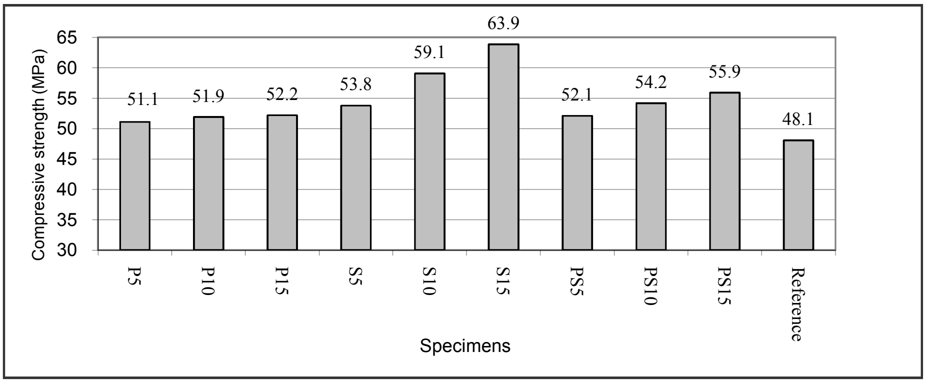


Figure 5. Compressive strength of specimens immersed in sulphate solution

The minimum compressive strength value was obtained in reference specimens whereas the maximum compressive strength value was obtained in S15 specimens. In this time period the compressive strength of S15 specimens was about 25% greater than that of reference specimens. In addition, compressive strength of specimens with blast furnace slag was higher than compressive strength of the other specimens in sulphate solution. These results are also supported by the previous studies [10].

***Permeability Values***

Specimens with 30 cm in length and 15 cm in diameter kept under water pressure of 10 atm for 7 days and no water flow has been found. Penetration depth of the water in concrete was measured in millimeters by dividing specimens in half. Permeability values are given in Table 8. Specimens hold at Sea showed similar permeability values with specimens that were kept in the laboratory on values of permeability. According to these results, all specimens, except specimens with pumice, had lower permeability values than reference specimens. The maximum permeability values were obtained from specimens with pumice especially in P15, the minimum permeability value was obtained in specimen S15 with 15% blast furnace slag. Specimens with pumice had higher permeability values compared to reference specimens due to permeable / porous structure of pumice.

Table 8. Permeability Values of Specimens ($x10^{-2}$)

| Specimens | 7 day | 28 day |
|---|---|---|
| R | 2,72 | 2,46 |
| P15 | 2,78 | 2,63 |
| P10 | 2,01 | 2,08 |
| P5 | 1,97 | 1,90 |
| S15 | 0,89 | 0,73 |
| S10 | 1,02 | 0,95 |

| | | |
|---|---|---|
| S5 | 1,00 | 0,81 |
| PS15 | 1,86 | 1,25 |
| PS10 | 1,72 | 1,21 |
| PS5 | 1,78 | 1,33 |

The following results were obtained from this study.

1. It was observed that using pumice in place of fine aggregate in production of concrete pipes led to an increase in ultimate load capacity. As amount of blast furnace slag increased, the ultimate load capacity of concrete pipes also increased. In this study, the optimal contribution rate of pumice was observed as 5%. Due to low specific gravity of pumice, use of pumice as fine aggregate in concrete pipes led to reduction in weight of concrete pipes. This will make it easier to obtain light-weight concrete pipes and reduce labor cost in installation of concrete pipes.
2. Although produced concrete pipes had the same dosage of cement, the ultimate load capacity of concrete pipes with blast furnace slag and pumice + blast furnace slag was 20% larger than that of reference specimens. The maximum increase in the ultimate load capacity of concrete pipes was obtained especially at 5-10% pumice + blast furnace slag substitution in place of fine aggregate.
3. Concrete pipes with granulated blast furnace slag + basaltic pumice and only blast furnace slag had the highest ultimate load value and the lowest permeability values. However, concrete pipes with only granulated basaltic pumice had the highest permeability value.
4. Specimens immersed in sulfate solution for 180 days and sulphate resistance of specimens was examined. Specimens with pumice and blast furnace slag had the minimum weight loss. Specimen S15 showed the best sulfate resistance whereas reference specimen showed the worst sulfate resistance. The weight loss decreased as the rate of substitution of pumice and blast furnace slag increases in specimens with pumice and blast furnace slag. These results suggest that pumice and blast furnace slag are sulfate resistant.
5. Compressive strength of specimens immersed in sulphate solution yielded similar results with the weight losses. Specimens with high weight loss had low compressive strength and specimens with low weight loss had high compressive strength. Reference specimen had the highest weight loss and lowest compressive strength whereas specimen S15 had lowest weight loss and highest compressive strength.
6. Depending on all these results, when concrete pipes with blast furnace slag and pumice used in sewage systems, they will extend the service life of the system. This will contribute to the country's economy. Concrete pipe production is a new area of use for basaltic pumice and blast furnace slag which exist in large amount in Turkey.
7. According to the results, granulated basaltic pumice and blast furnace slag can be used in place of fine aggregate in production of concrete pipes for wastewater and sewage system where various destructive acids or salts can exist.Thus, aforementioned chemical degradation could be avoided or its effect level could be reduced.

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