

# **Utilization of Waste Glass, Fly Ash, Metakaolin and Silica fumes in Paver Blocks**

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Submitted by

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## DECLARATION

I Vishal Kumar hereby declare that the thesis entitled “Utilization of Waste Glass, Fly Ash, Metakaolin and Silica fumes in Paver Block” is an authentic record of my studies carried out as requirement for the award of degree of Master of Engineering (Structural Engineering) under the supervision of **Dr. Himanshu Chawla**, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and Technology, Patiala. The matter embodied in this report has not been submitted in part or full to any other institute or university for the award of any degree.

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## Certificate

This is to certify that the above declaration made by the student concerned is correct according to the best of my knowledge and belief.



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## ABSTRACT

The waste coming out of thermal power plants and during the production of silica and its alloys results in a large amount of waste that requires disposal in controlled landfills. Consequently, the financial and environmental costs of landfilling are very high. However, these by-products/waste can be used as supplementary cementitious material (SCM) instead of being disposed or landfilled. Similarly, waste cullet can also be used as the supplementary material in concrete paver blocks as a partial replacement of sand. Therefore, this study aimed at developing an eco-friendly precast concrete product by enhancing the application of waste glass, fly ash, metakaolin and silica fumes. The waste glass was utilized as a partial replacement of sand. Fly ash, metakaolin and silica fumes is utilized as a partial replacement of cement in the paver blocks. It is observed that for a constant water-to-cement ratio, compressive strength increases with the partial replacement of cement with waste supplementary cementitious materials. The highest increase in strength is at the 15% replacement of cement with fly ash, silica fumes and metakaolin. On the other hand, in case of replacement of natural sand with glass cullet, highest increase in the strength is obtained at the replacement level of 10%.

The flexural strength of the paver blocks increases with addition of glass cullet, fly ash, metakaolin, silica fumes is added in the mix. The maximum increase in the flexural strength is observed in the specimens in which 15% cement is replaced with supplementary cementitious material. On the other hand, 10% replacement of sand with glass cullet the flexural strength obtained is higher than other replacement level. In case of blocks having partial replacement of cement and sand, highest flexural strength is obtained when the replacement level of cement is with 15% fly ash and 10% sand is replaced with glass cullet. The most importantly, enhancement in the strength is double as compared to the controlled specimens.

The water absorption coefficient obtained for all the mix is well below the IS: 15658 (2006) specifications. So, all the mixes pass the Indian standards for water absorption test. The combined use of glass cullet and pozzolanic waste materials was beneficial in reducing the water absorption paving blocks within permissible limits. Moreover, the addition of waste materials also enhances the flexural and compressive strength of the paving blocks.

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## 1.1 General

In the 1950, concrete blocks were first introduced in Holland as a replacement to conventional brick paving blocks due to its strength better properties and use in construction practices in later war era period. Size dimension of these blocks are similar to brick specimens and are rectangular in shape. The shapes of the block have slowly changed from non-interlocking to incompletely interlocking to completely interlocking to multiply interlocking shapes during past five decades.

India is a developing country so there is a huge call for construction of roads, buildings etc. There is brisk development of basic infrastructure and housing continuously taking place in India from last one decade. Along with that naturally, there is a rapid demand of material required for development of infrastructure and housing to meet the demand of the growing population. As a result, the mass quantities of products like interlocking concrete paving blocks (ICPB) are manufactured, which are the industrial products of precast made up of concrete of varied shapes and sizes used in huge quantity in housing, roads and infrastructure construction. Interlocking concrete paving blocks finds its use in multiple fields and has pleasing surfaces, durable, economic in design and requires very less maintenance if produced and arranged properly. Interlocking concrete paver blocks are the modern-day solution of rigid and flexible pavement. Interlocking concrete pavement are mostly used in areas requiring higher concerns of environmental factors, operational used in the specified fields compared to traditional brick paving blocks. Interlocking concrete block pavements showed their strong possible alternatives to conventional flexible as well as rigid pavements. Due to its higher strength properties, higher wear and tear resistance and toughness, it received greater interest in areas having municipal, industrial or governments buildings. These paver blocks can be used as a substitute for flexible and rigid pavement. Interlocking paver blocks has very less cost of maintenance and can be easily replaced with a new concrete paver block at time of breakage. Countries using interlocking concrete paver blocks in various fields of construction or pavement are mainly China, United states, Japan, Pakistan and India etc. In United States, paver blocks of concrete were developed prior to the world war 2 by the Dutch researchers and later on introduced in the United states in the early 1970s. In India, ICPB technology of construction of pavement made their presence in early 2000's for their demands in footpaths as well as parking areas. But their versatile nature leads the designers to use the paving blocks in traditional bituminous

pavement and cement construction cannot be laid. Most interlocking concrete paving block produced in India has performed satisfactorily. But the main cause of their failure is occasional failure of the upper abrasive layer due to high surface wear, and changes in the strength due to uniform or non-uniform compression loading. Interlocking concrete paver are manufactured from semi-dry mix of precast concrete which are commonly used in construction of pavement. As we know for the pavement installed using blocks should have high compressive strength. During the industrial manufacturing of paver blocks vibration as well as pressure are given to the mix. As a result, we get stronger and denser concrete blocks which can be used to get stronger and long-lasting paving surface. According to Indian standard code 15658:2006 the standard thickness of paver blocks which is used in India are: -

1. 50 mm for no- traffic.
2. 60 mm for light traffic.
3. 80 mm for heavy traffic.

Paving block composition consists of FA, coarse aggregates of 10mm which form the bulk whereas cement, water and superplasticizer etc are used in limiting quantities. Interlocking concrete pavement are constructed from individual solid blocks to form a smooth pavement surface. Concrete block pavements (CBPs) are installed over sub base of compacted stones and levelling thin bed of sand. Paver blocks used in CBPs are of classified according to various shapes and sizes as well as design patterns. The spacing between the paver blocks used for construction of pavement are then filled with specified graded sand. Both side of paver blocks are restrained by the edge restraints. The interlocking behaviour of paver block in pavement gives the ability to spread the load acting on the surface of pavement to large area.

## **1.2 Various advantages of CBPs over both rigid and flexible pavement are given below:**

1. Laying of CBSs as compared to traditional pavements is easy
2. Laying of pavement is done in very small duration of time as compared to rigid or flexible pavement
3. Low cost of maintenance and can be easily replaced with new one at the time of breakage
4. Life span is more
5. Easy to transport
6. Curing is done before laying due to which it gets its own strength before even laying of pavement

### **1.3 Manufacturing of Paver blocks using industrial waste**

Interlocking concrete paver are manufactured from semi-dry mix of precast concrete which are commonly used in construction of pavement. As we know for the pavement installed using blocks should have high compressive strength. During the industrial manufacturing of paver blocks vibrations in accordance with applied pressure is given to the mix as a result we get stronger and denser concrete blocks.

### **1.4 Material used**

Water, cement, sand, fine-aggregates and coarse-aggregates are the basic materials needed for the manufacturing of concrete. Due to the world-wide interest in solving the environmental problem of pollution and waste materials produced by industries. Construction industry has to support the world on this rising pollution and waste problem produced by industries. This can be done by using this industrial waste and other material in the manufacturing of concrete and other construction industry related products like paver blocks. There are various pozzolanic materials that can be used as a supplementary cementitious material produced as waste by different industries in the concrete like fly ash, silica fumes, fine crushed glass and metakaolin. Crushed glass can be used as sand replacement. In this study effort was made to use by-products of different industries for creating paver blocks by exchanging cement with fly ash, metakaolin, silica fumes and replacing natural sand with crushed glass.

#### **1.4.1 Cement**

Cement is the prime ingredient required for the concrete it is used as a binder. A binder is a material used during construction process that set, hardens and bond with other construction material to reinforce them together. Cement binds the sand and gravels with each other to give the desired engineering material. In the concrete it is very rare to use the cement on its own. Geopolymer cement and Portland cement are the two forms of cement which are generally used. According to IS 456: 2000,  $450 \text{ kg/m}^3$  is the maximum content of cement that can be used in the mix design of concrete. When OPC is used the quantity of cement should not be less than  $360 \text{ kg/m}^3$ . Cement are usually characterized by their ability to set in the presence of water i.e. hydraulic or non-hydraulic. Non-hydraulic cement set in dry conditions. They react with carbon dioxide present in air and sets. They do not set under wet condition or under water. They are resistant to chemicals after setting. Hydraulic cement becomes adhesive as the dry

ingredients and water interact with each other chemically. Portland cement is type of hydraulic cement.

The three different grades of cement generally used in the construction are 33-grade, 43-grade and 53-grade. In this study, cement grade 43 is used for the casting of paver blocks. The composition of ordinary portland cement's is given in the Table 1.1.

**Table 1.1.** Chemical configuration of cement

Lime (CaO)	60-64%
Silica (SiO <sub>2</sub> )	18-24%
Alumina (Al <sub>2</sub> O <sub>3</sub> )	2-8%

## **1.4.2 Aggregates**

Generally, the coarse and FA inhabit 60% -75% volume of concrete or 70-85% in terms of mass due to which they strongly influence concrete's freshly mixed and hardened properties, cost effectiveness and mixture proportions. Fine aggregates generally consist of crushed stone or natural sand with most particles smaller than 5 mm or 0.2 inches. Coarse aggregates are mainly combination of particles of various materials like crushed stones and gravels. The size of particle is larger than 5mm or .2 in and usually between 9.5 mm and 37.5 mm or 3/8 and 1 1/2 inches.

### **1.4.2.1 Fine-aggregates**

Fine aggregates generally consist of crushed stone or natural sand with most particles lesser than 5 mm or 0.2 inches and should follow IS: 383 (1970). Fine aggregates should not contain any organic matter, clay, soft particle and any other foreign matter.

#### **1. Sand**

Sand is a granular material. It is decomposed product of rocks and minerals in there finally divided form. The shape and the size of sand particles depends upon the source from where it is obtained.

##### **i. River Sand**

This type of sand is obtained from bank or bed of the river. Giver sand can be coarse or fine. River sand is preferred over finer sand because it contain less dust. River sand offers numerous

applications over artificial sand like mixing of plaster as river sand particles are rounder than artificial sand it creates much smooth and finished surface.

## ii. Pit or Coarse Sand

Pit sand is not same as the sand found on the beach. The particle size of pit sand is larger. It does not contain any organic matter. Pit sand is the best type of sand used in the mortar or concrete during construction. The particle shape of pit sand is usually Sharpe and angular. Pit sand is obtained by digging it out from natural resources in the earth. It is usually used in mortar because it creates strong cement.

**Table 1.2.** Fine aggregates as per IS:383 (1970).

IS Designation	Percentage passing for			
	Grading zone I	Grading zone II	Grading zone III	Grading zone IV
10mm	100	100	100	100
4.15mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-10	85-100	90-100
1.18mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

## 2. Crushed waste glass

Glass cullet is a waste material and can be obtained from many sources. Then it is grinded to same size as construction sand it shows the same properties as the sand.

### 1.4.2.2 Coarse aggregate

Coarse aggregates are combination of crushed stones and gravels. The size of particle is larger than 5 mm and usually ranges between 9.5 mm - 37.5 mm. Water absorption of CAs should not be more than 2% or it will not be used in the concrete mix. No aggregates shall have joint elongation and flakiness index above 35%. For soundness test aggregates will be tested according to IS:2386(part-5).

### 1.4.3 Metakaolin

Metakaolin is relatively a new material then the fly ash in the concrete industry shown in Fig 1.1 having greater efficiency in increasing compressive strength, increase sulphate resistance and can also improve air void network of the concrete. When blended with cement can provide many specific features to concrete. Metakaolin is produced when pure, clean or refined kaolinite clay is calcinated at temperature varying between 650° C to 850° C, then the obtained material is grinded up to fineness of 700-900 m<sup>2</sup>/kg. Metakaolin also shows pozzolanic properties, which can be used as a substitute of cement in the mix, given at proper proportion metakaolin improves life of the of concrete. It also makes the concrete impervious as it fills the void space between the cement particles. Microstructure of concrete changes while undergoing pozzolanic reaction. It also consumes the hydration products released i.e. it consumes calcium silicate hydroxide (C-H-S) and calcium hydroxide (C-H), resulting in additional increase in strength.



**Fig. 1.1.** Metakaolin

### 1.4.4 Silica fume

Silica fume is a waste emitted during the production of silica or its alloy. A very tiny amorphous-silica particles are formed in the arc furnaces it is also known as condensation silica fumes/micro silica. It is also produced during the production of ferro-chromium, calcium-silicon, ferro-manganese, ferro-magnesium. In early 1970s mostly all silica fumes were released into the air. But now it is collected and used in many applications. The specific area of silica-fumes is 20000 m<sup>2</sup>/kg as compared with 450 - 800 m<sup>2</sup>/kg for fly ash and for ordinary Portland cement it is 300 m<sup>2</sup>/kg to 550 m<sup>2</sup>/kg. Average size of the fumes is 100 times lesser than cement particles. Due to silica content and high fineness it acts as very good pozzolanic material, when silica fumes are blended with cement in proper proportion it can enhance the

durability, abrasion resistance. It also limits the permeability and protect reinforcement against corrosion concrete made using silica fumes show less bleeding. Durability of concrete increase, because porosity decreases as we increase silica fumes in concert. Cement can be replaced with silica fumes up to 15% by weight of cement, but ideal proportion is 7% to 10%. With the replacement of 15% cement with silica fumes it makes strong concrete but it may also make concrete brittle.

**Table 1.3.** Chemical-composition of silica-fume.

<b>Constituents</b>	<b>Percent (%)</b>
Silicon-dioxide (SiO <sub>2</sub> )	87-95
Aluminum-oxide (Al <sub>2</sub> O <sub>3</sub> )	0.5-0.7
Magnesium-oxide (MgO)	0.6-1.5
Iron-oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.3-0.9
Calcium-oxide (CaO)	0.1-0.4
Sodium-oxide (Na <sub>2</sub> O)	0.3-0.6
Potassium-oxide(K <sub>2</sub> O)	0.3-1.2
Carbon (C)	0.4-1.3
Sulfur (S)	0.2-0.4

#### **1.4.4.1 Production of silica fumes**

Silica fumes are emitted in the electric arc furnaces at the time of manufacturing of silica metal or ferro silica as a by-product of manufacturing process. The fumes are collected the filtering the exhaust gases escaping from the furnaces and very fine particles of silica dioxide are collected.

#### **1.4.5 Fly ash**

Fly ash is the by-product generated during the burning of coal in coal fired thermal power plants to generate electricity. It is captured by electro static precipitators system or filtration systems before the flue gases escape the chimney. It is combined with Portland cement to increase the strength properties. It advances concrete properties in hardened state as well as fresh state. It is economical to use. Blending of fly ash in cement enhance workability, and compressive as well as flexural strength of the cement concrete. It also increases durability of cement concrete. The amount of Portland cement may decrease as we add fly ash in it.

### 1.4.5.1 Benefits to fresh concrete

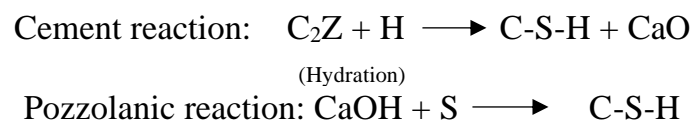
Fly ash enhance the workability of the freshly designed concrete mix. When replaced in the mix it also lessens the water content required in the concrete. The resulting benefits of fly ash addition in concrete are as follows:

- 1. Improved workability.** Spherical shape of the minute fly ash particles acts as tiny bearing ball within the concrete mix, thus acting as lubrication in the concrete mix. It also increases concrete pumpability as the frictional losses during the process of pumping is minimized due to the spherical nature of fly ash particles.
- 2. Decreased water demand.** Water demand of the cement can be reduced by replacing cement with fly ash for a given slump. Approximately 10 percent water demand is reduced, when 20% fly ash is used as total cementitious material. On higher addition of fly ash content higher water reductions is yielded. The low water demand has little effect on drying shrinkage and cracking.
- 3. Reduced heat of hydration.** Heat produced during curing of concrete is reduced by adding fly ash.

### 1.4.5.2 Benefits to hardened concrete

Additional cementitious compounds are produced when fly ash react with alkali and lime available in the cement concrete. Chemical reaction occurred during addition of fly ash lead to formation of more calcium silicate hydrate (CSH) gel which in turns enhance the mechanical properties of concrete.

### 1.4.5.3 Pozzolanic reaction of fly ash



Pozzolanic reaction of fly ash has huge impact on hardened properties like:

1. Reduce permeability.
2. Improved durability.
3. Increased ultimate strength.

#### **1.4.6 Water**

The water used in the mix should be free from debris and should be clear. Value of pH should lie between 6.5-8.

#### **1.5 Physical Requirements**

According to IS 15658 (2006) concrete having zero slump value can be used in the manufacturing of the concrete paving blocks. So, the various parameters on which the quality of produced paver block depend are

1. Method adopted during curing of blocks.
2. Quality control achieved and workmanship.
3. Additives used
4. Degree of compaction.
5. Cements grade used in blocks.
6. Water cement ratio (water content).
7. Compaction applied
8. Vibration given to the mixture.
9. Type and specification cement used.

According to IS: 15658:2006 (clause 5 and 9.1.4) the recommended grade for paver block for different traffic categories and the corresponding thickness of blocks are given in the table above.

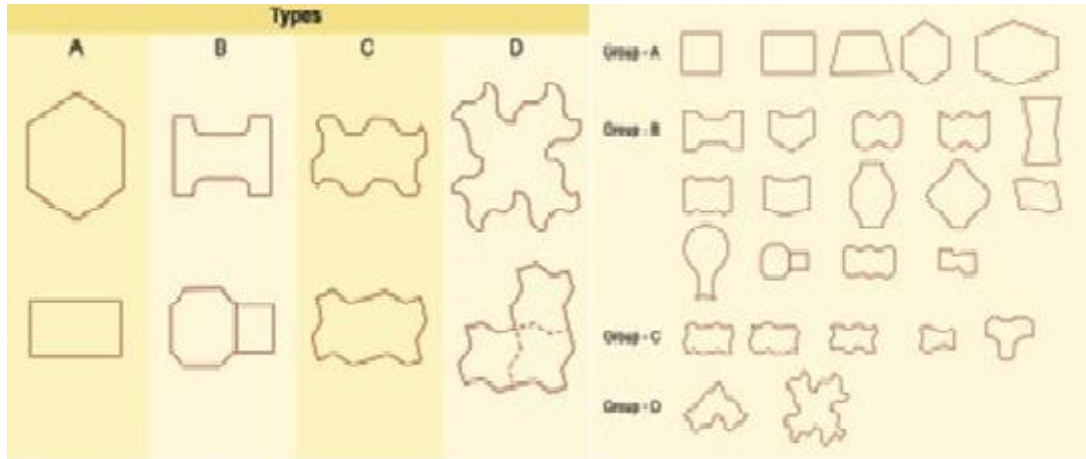
#### **1.6 Groupings of paver blocks**

Generally, four basic forms of blocks are used in accordance with four specific types of blocks. Classification of blocks with respect to shapes and types specification are stated as below: -

1. **Type A:** These concrete paver blocks have smooth straight faces, cannot interlock with each other in any pattern.
2. **Type B:** These concrete paver blocks have discontinuous shape on sides and have rounded/grooved vertical faces. When laid in any possible formation can interlock with adjacent blocks along the bend/grooved faces.
3. **Type C:** Paving blocks of these class has all sides rounded or grooved and possess discontinuity greater than class B paving blocks. These blocks when laid in any direction can interlock into one other positioned along the vertical plains.

4. **Type D:** These paver blocks have 'L' and 'X' shapes and have all faces rounded or grooved and can interlock into each other along the vertical plains when laid in any direction.

In our study, type-B shape, i.e., dumbbell shaped paver block is used.



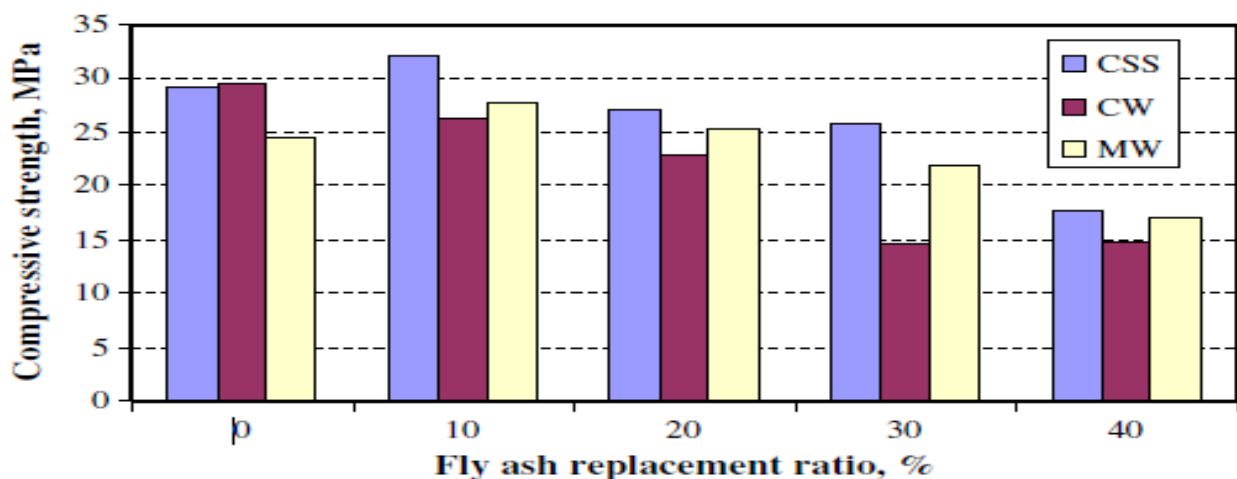
**Fig. 1.2.** Classified shapes and type of concrete paving blocks

### 2.1 General

In the literature, the effect of using numerous waste material as a partial replacement of cement and FA in the construction of concrete pavement block is available. It's effect on mechanical properties is reviewed and presented in this study below.

### 2.2 Compressive strength

Uygunog *et al.* (2012), observed the effect of partial substitution of cement and sand on the mechanical properties of paver blocks. Author also observed the effect of replaced waste on the alkali silica reaction. Concrete interlocking paver are prepared by substituting cement with fly-ash concentrations ranging between 0%, 10%, 20%, 30% and 40% and also partially replaced the FA with sand stone (crushed), concrete and marble waste. Concrete blocks of size 200 x 200 x 80 mm were fabricated. It is noted that on increasing the fly ash content in concrete considerable reduction in compressive strength was observed. Only the specimen at 10% shows higher crushed marvel or concrete waste the compressive strength of the block decreases. Crushed sand stones give the best results out of all the waste materials used in the mix. In comparison to the controlled specimen increase in strength was compared. The strength of the block specimen of crushed marble, concrete and sand stone waste varied between 32.1 to 17.7 MPa, 27.8 to 17.1 MPa and 29.6 to 14.6 MPa respectively. Fig. 2.1 represents the relationship between compressive strength and percentage replacement of specimens.



**Fig. 2.1.** Compressive strength of concrete blocks versus fly ash content (Uygunog *et al.* 2012).

*Gencel et al. (2012)*, has analysed the effect of partial replacement of coarse and FA with waste materials on the mechanical and physical properties of paver blocks. In his study two different grades of cements are used. Concrete blocks are prepared by partial replacement of aggregates with marble aggregates at 10%, 20%, 30% and 40%. It was concluded that as the percentage of marble aggregates goes on increasing in the mix, there is reduction in the compressive strength of the concrete paving block.

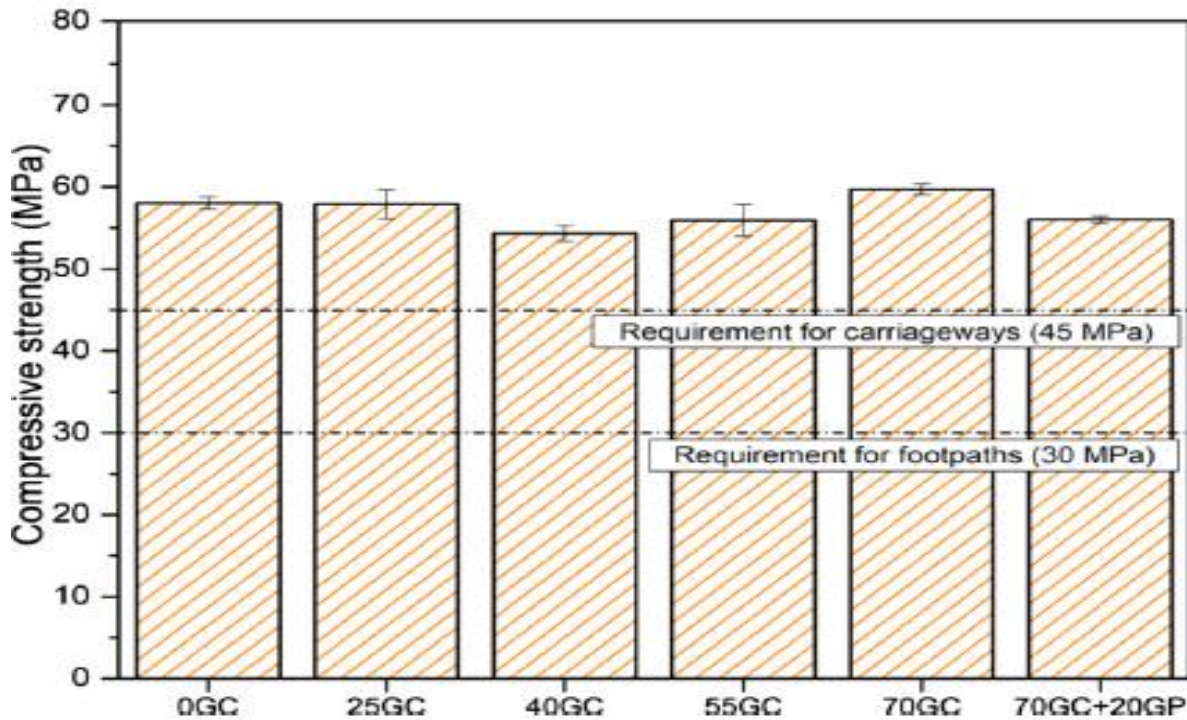
*Sadek et al. (2013)*, studied the effect of waste ceramic as a partial substitute to coarse and FA on the various mechanical and physical tests. It is observed that when fine aggregates in upper abrasive layer is replaced with 50% and 100% with the ceramic waste. Then, there is an increase in the compressive strength of 103 MPa and 132 MPa respectively when compared with the controlled mix. When the fine aggregates are replaced with fine ceramic in the lower layers the compressive strength of the specimen increases by 109% and 107% when compared with controlled specimen. Hence, it is concluded that the ceramic can be used for the production of paver blocks as a substitute of FA. Table 2.1 shows the compressive strength of paver blocks for different proportions of ceramic waste in abrasive and lower layer of the concrete block.

**Table 2.1.** Compressive strength of block at different proportions of ceramic waste (Sadek et al., 2013).

<b>Percentage of ceramic in upper Abrasive layer</b>	<b>Percentage of ceramic in Lower layer</b>	<b>Compressive strength (N/mm<sup>2</sup>)</b>
0	0	38.76
0	50	33.74
0	100	23.89
0	50	41.78
0	100	41.36
50	50	30.73
50	0	42.24
100	0	52.04

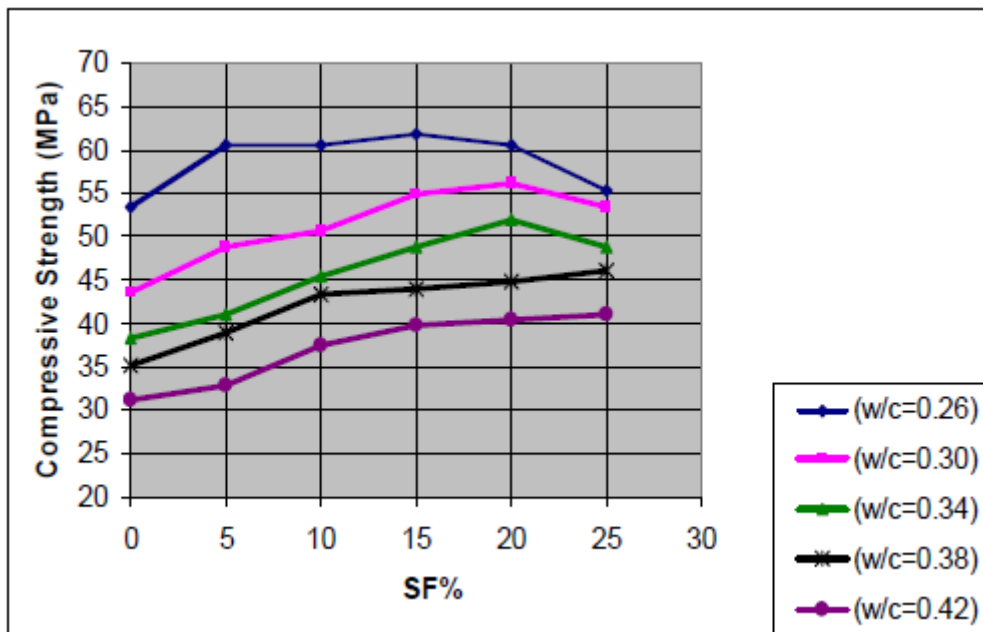
*Lu et al. (2019)*, has studied the effect of replacing waste glass with the cement and fine aggregates. Concrete blocks are prepared by partial replacement of cement and FA with fine and coarse glass cullet. During the preparation of specimen 20% cement is replaced with glass cullet and fine aggregate with 0%, 25%, 40%, 55% and 70% glass cullet. It is noticed that there

is no effect on the compressive strength of paver blocks takes place when FA are replaced with glass cullet from 10% to 70% by weight in the concrete. But when cement is partially replaced with 20% glass cullet there is slightly decrease in the compressive strength of specimens. This reduction in strength is due to very slow pozzolanic reaction of glass at the early age.



**Fig. 2.2.** Compressive strength of block when replaced with glass cullet and glass cullet (Lu et al. 2019)

*Katkhuda et al. (2009)*, observed the behaviour of partial replacement of cement with silica fumes on the mechanical properties of concrete like flexural, tensile and compressive strength of concrete. They have partially replaced the cement with silica fumes i.e., 5%, 10%, 15%, 20% and 25% for water cement ratio of 0.42. The maximum compressive strength is obtained for partial replacement of cement in ranges between 15% - 20%. It also depends on the water-cement ratio as shown in Fig. 2.3 respectively. The optimal percentage of silica fumes addition increases with the increase of water cement ratio.



**Fig. 2.3.** Compressive strength of block when replaced with glass cullet and glass cullet (Lu et al. 2019)

**Table 2.2.** Compressive strength of mix with glass cullet (Malik et al., 2014).

Percentage of waste glass	Compressive strength (N/mm <sup>2</sup> )	
	7 days	28 days
0	21.48	28.07
10	24.29	33.69
20	24.73	35.11
30	22.37	30.82
40	18.07	25.69

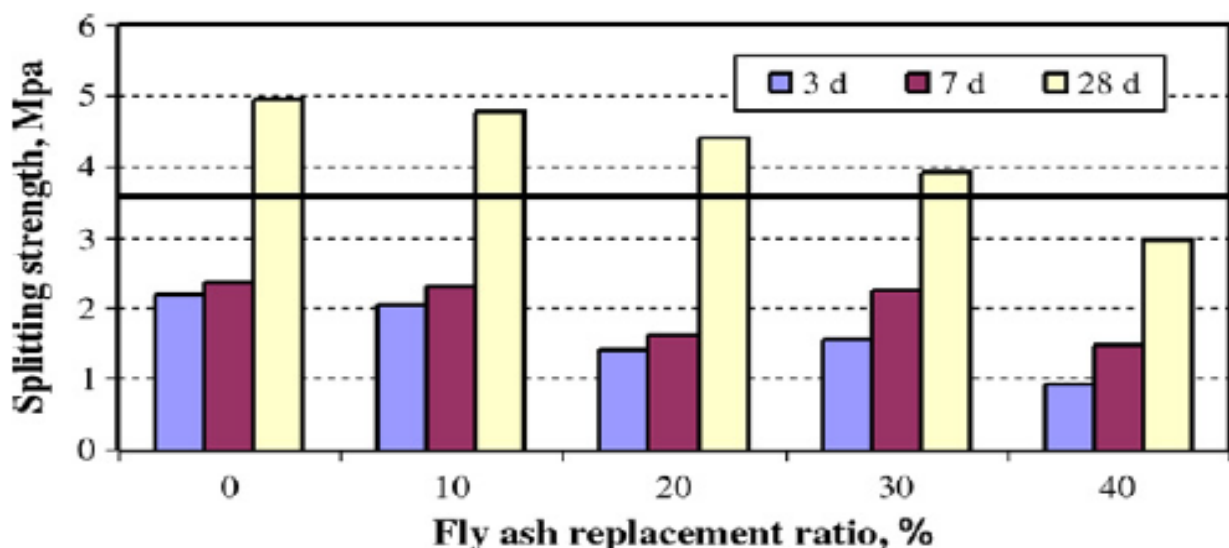
Malik et al. (2014), studied the compressive strength of 150 x 150 x 150 mm cube specimens at 7days and 28days of age. He checked the compressive strength of cubes by replacing the 10%, 20%, 30% and 40% sand by glass cullet by weight. The w/c ratio was kept 0.45. He also studied the water absorption of different proportions of mixes and concluded that the percentage of absorption of water decreases with increase in glass cullet content. The most minimal value of water absorption was found for the concrete mix which has 40% of glass cullet. The compressive strength of the different cube specimens is shown in the Table 2.2 below.

From the above Table 2.2, it was found that the highest achievable strength of cube sample was at 20% by glass cullet. The strength increases by 25% which is approximately the strength of

M35 grade of concrete, therefore the optimum glass cullet content in concrete mix is 20% by weight. The results also showed that after 40% replacement there was no significant change in strength when compared with the control mix so the replacement should be limited to 30% by weight of the aggregates.

### 2.3 Split-tensile strength

Uygunog *et al.* (2012), has conducted the study on concrete blocks. In this study the cement is partially replaced with cement. In addition, sand is also replaced with 3 different materials, crushed sand stone marvel and concrete waste as a partial replacement of fine-aggregates. In this study He performed investigation on mechanical and physical tests on the concrete. And it is observed that the concrete blocks show low strength in early ages. But on prolonged curing periods, increase in the strength of the paver blocks was observed. It was also noticed that strength of block increases with increase of the curing period for all the waste materials, despite of the fly ash. The strength varied from 55.6% to 68.8%, 43.7% to 43.3% and 31% to 51% for crushed sand stone, marvel waste and concrete waste respectively, depending on fly ash content. Concrete waste and marvel waste attain more strength as compared to sand stone in premature period at 3 and 7 days of curing. Fig. 2.4 to 2.6 displays the split-tensile strength of the block specimens after the curing period of 3,7 and 28 days for different replacements of cement and fine-aggregates.



**Fig. 2.4.** Tensile strength paver blocks versus fly ash content for crushed send stones (Uygunog *et al.* (2012)).

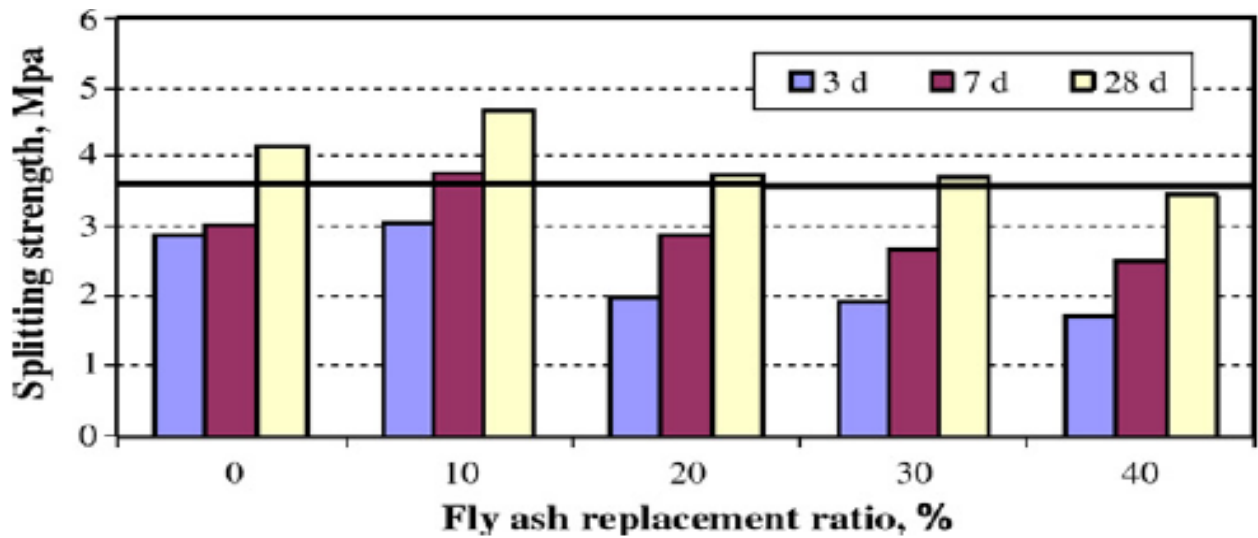


Fig. 2.5. Tensile strength of paver blocks versus fly ash content for crushed sand stones (Uygunog et al. 2012)

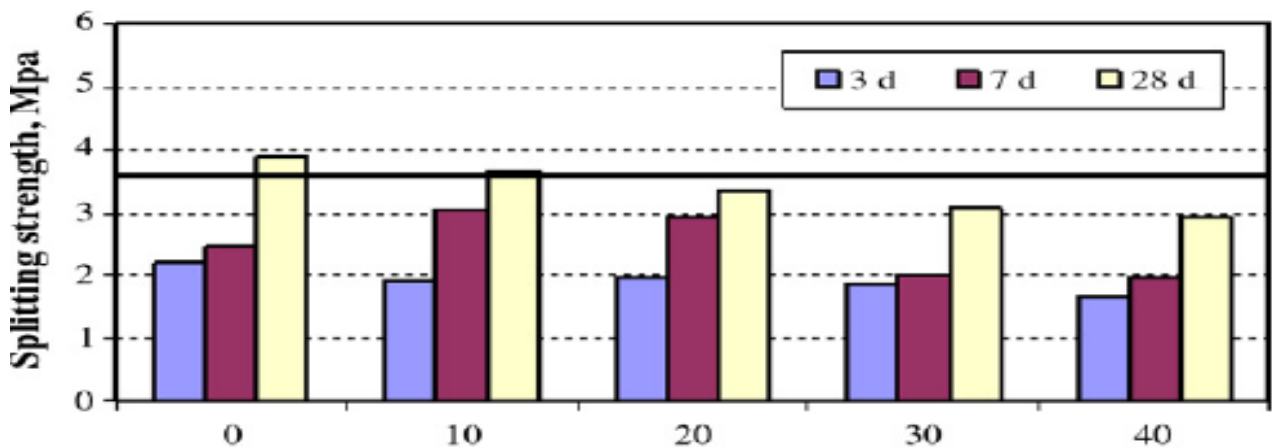


Fig. 2.6. Tensile strength of blocks versus fly ash content for concrete waste. (Uygunog et al. 2012)

Sadek et al. (2013), studied the effect of waste ceramic as a partial substitute to the coarse and FA on compressive strength, tensile strength and water absorption test. It is observed that when fine-aggregates in upper abrasive layer is replaced with 50% and 100% with the ceramic waste. None of the specimen or mix reach the value of minimum strength of  $3.6 \text{ N/mm}^2$ . The only mixes to please the standards where 50% finely divided crushed ceramic that are laid in bottom layer. Another effect observed when abrasive layer is replaced by 100% fine crushed ceramic. All the block specimens pass the second standard of minimum load which should be greater than  $250 \text{ N/mm}^2$ . Furthermore, the specimen with 50% crushed fine sand in the lower layer and 100% crushed fine sand in the abrasive layer have the best results. Both the mix have the maximum failure load. Table 2.3 shows the result for tensile strength for different proportions of ceramic in upper abrasive layer and lower layer.

**Table 2.3.** Ceramic waste specimen compressive strength by different proportions (Sadek et al., 2013)

Percentage of ceramic in upper Abrasive layer	Percentage of ceramic in Lower layer	Splitting tensile strength (N/mm <sup>2</sup> )	Failure load (N/mm)
0	0	3.20	400
0	50	2.40	303
0	100	1.80	227
0	50	3.60	440
0	100	2.40	306
50	50	2.30	290
50	0	2.30	292
100	0	1.07	432

Malik et al. (2014), observed the tensile properties of concrete samples by making the cylinders having specimen size 150mm x 300mm. Curing period of the concrete samples were 7 and 28 days, respectively. Splitting tensile strength taken at 7 and 28 days, respectively was compared with the conventional concrete. But in his research, there was no increase in strength by replacing sand by glass cullet. The split tensile strength was inversely proportional to the amount of sand replaced by glass cullet. The splitting tensile strength of various cylinders of different concrete mixes are shown in Table 2.4 for curing period of 7 and 28days.

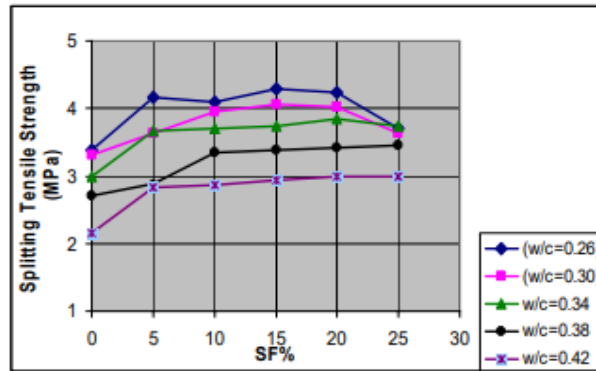
From the results it can be concludes that sand should not be replaced by glass cullet because the strength decreases when it is replaced by glass cullet. The conventional concrete has maximum tensile strength as compared to all other mixes which have glass cullet, therefore conventional concrete is more efficient in taking tensile stresses than glass cullet concrete cylinders.

**Table 2.4.** Split tensile strength (Malik et al., 2014).

%age of waste glass replacement	Tensile strength (N/mm <sup>2</sup> )	
	7 days	28 days
0	2.12	28.07
10	2.08	33.69
20	2.02	35.11
30	1.80	30.82
40	1.60	25.69

Katkhuda et al. (2009), studied the effect of silica fumes on replacing with the cement. Mechanical properties of the concrete samples like flexural properties, tensile properties and

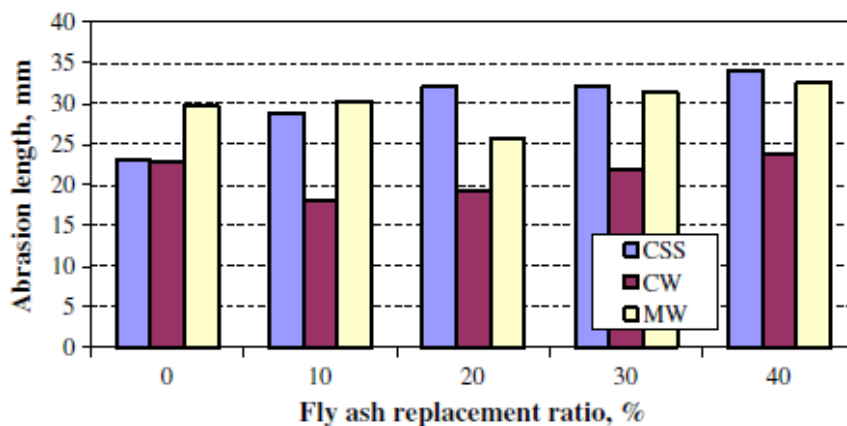
compressive strength properties of concrete blocks were studied by partial replacement of cement with silica fumes at 5%, 10%, 15%, 20% and 25% for water cement ratio of 0.42. The maximum compressive and flexural strength is obtained at the replacement of 15%-20%. It also depends on the water cement ratio as shown in Fig. 1.4 respectively. The optimal percentage of silica fumes addition increases with the increase of water cement ratio.



**Fig. 2.7.** Tensile strength at 28 days by silica fumes replacement (Katkhuda et al. 2009)

## 2.4 Abrasion resistance

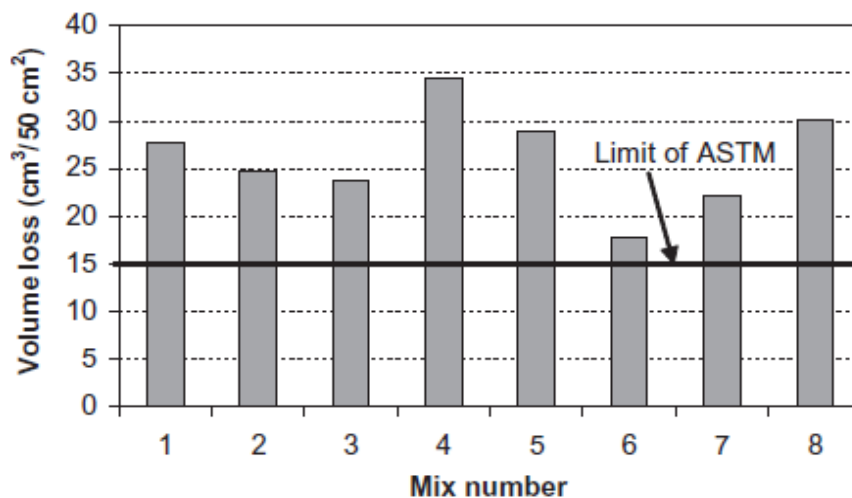
Uygunog *et al.* (2012), observed mechanical properties of paver blocks by replacing cement and FA in limited amounts. Author also observed the effect of replaced waste on the alkali-silica reaction. Replacing fly-ash with cement at 0%, 10%, 20%, 30% and 40% were tested for mechanical properties, replacement was also done for FA with sand stone (crushed), concrete and marble waste. Compressive strength of concrete sturdily effects the abrasive strength of the paving blocks. All the properties of the paver block decrease on partial replacement of concrete waste but the wearing resistance of the specimens increases. The results of the test can be seen in Fig. 2.7 above.



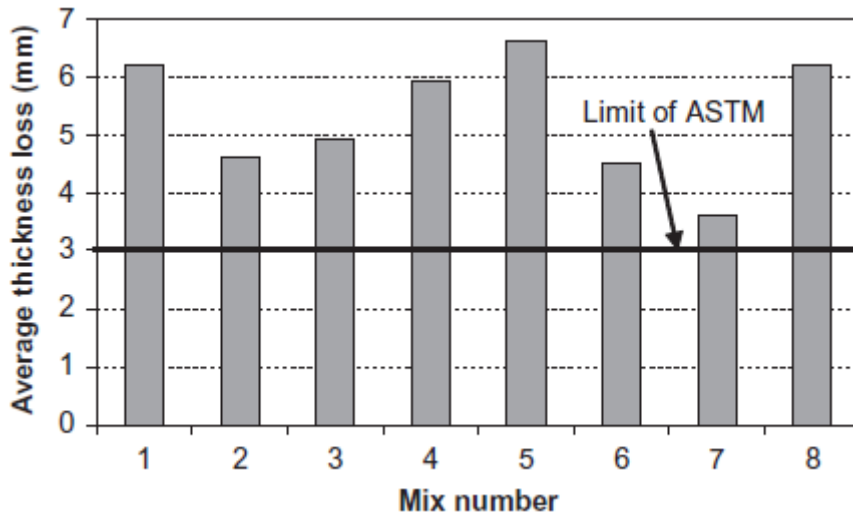
**Fig. 2.8.** Abrasion resistance of blocks when replaced with crushed sand stones, concrete waste (CW) and marble waste (MW) (Uygunog et al. 2012)

*Gencel et al. (2012)*, has studied the mechanical and physical properties of waste materials by partial replacement of coarse and FA of paver blocks. In his study two different grades of cements are used. Concrete blocks are prepared by partial replacement of aggregates with marble aggregates at 10%, 20%, 30% and 40% in the concrete mix. It is observed that the abrasion resistance of the concrete block increases marble is added in the mix. This is because of the higher hardness of the marble aggregates.

*Sadek et al. (2013)*, studied the effect of waste ceramic mechanical and physical properties on replacing it with coarse and FA. Compressive strength, abrasion resistance test, tensile strength and water absorption test were performed. It is observed that when the abrasive layer of paver block is partially or fully replaced with ceramic waste. All the test specimens tested for abrasion resistance fail as per the specifications of ASTM. The loss in the average thickness of wearing layer is in the range of 3.6-6.6 mm. But, when the partial replacement of wearing layer is done with 50% fine crushed ceramic then the wearing resistance of the concrete increases. The loss in volume of the block specimen are in the range of 17.8 cm<sup>3</sup>/50 cm<sup>2</sup> to 34.5 cm<sup>3</sup>/50 cm<sup>2</sup>. Fig. 2.9 and 2.10 shows the change in volume and thickness of the specimen.



**Fig. 2.9.** Relationship between replaced ceramic waste and its effect on volume loss of specimen after abrasion testing (Sadek et al. 2013)



**Fig. 2.10.** Relationship between replaced ceramic waste and its effect on the thickness of specimen during Abrasion testing (Sadek et al. 2013)

**Table 2.5.** Compressive strength of blocks with replacement of sand with ceramic waste (Sadek et al., 2013).

Percentage of ceramic in upper abrasive layer	Percentage of ceramic in Lower layer	Compressive strength (N/mm <sup>2</sup> )
0	0	38.76
0	50	33.74
0	100	23.89
0	50	41.78
0	100	41.36
50	50	30.73
50	0	42.24
100	0	52.04

## 2.5 Water Absorption

*Pattnaik et al. (2018)* investigated the effect of partial replacement of cement by fly ash and waste glass by mass. Authors have prepared the paver block of thickness 80 mm thickness. The test on the blocks is done on the basis of IS 15658:2006 (ANNX E). In this study five mixes designs were used to check the properties of the block specimens. In the first mix 10% cement and 10% sand is replaced, in second 20% both cement and sand are replaced, in third 30% and in fourth 40% of both cement and sand, respectively partially substituted with fly ash and glass

cullet. The last mix is the standard mix with no replacement. The results of the abrasion test are given in the Table 2.5. It is observed that the depth of wearing layer decreases by substituting it with cullet of glass and fly ash increase by 30% with respect to controlled specimen. At replacement level of 40% the depth of wearing layer slightly increase then the controlled specimen.

**Table 2.6.** Abrasion test (Pattnaik et al. 2018).

Age, Days	Abrasion Value, mm				
	Variation of fly ash and glass powder replacement with cement				
	MFG(0)	MFG(10)	MFG(20)	MFG(30)	MFG(40)
28	1.58	1.54	1.53	1.51	1.63
56	1.58	1.55	1.53	1.51	1.68



**Fig. 2.11.** Rubber mould used by Pattnaik et al. (2018) in study

*Lu et al. (2019)*, observed the effect of waste glass on partial replacement by cement and fine-aggregates. Concrete blocks are prepared by partial replacement of glass cullet and glass cullet with cement and FA. During the preparation of specimen 20% cement is replaced with glass cullet and fine aggregate with 0%, 25%, 40%, 55% and 70% glass cullet. It is observed that the water absorption of the block decrease with partial addition of glass cullet as FA it does not exceeds the Hong Kong specifications of 6%. On, further replacement of cement with glass cullet there is further reduction in water absorption rate of the specimen.

*Uygunog et al. (2012)*, has studied the effect of fly ash by replacing it with cement and noticed the mechanical properties of paver blocks. Author also observed the effect of replaced waste on the alkali silica reaction. Concrete interlocking paver are prepared by partial replacement of cement with fly-ash at 0%, 10%, 20%, 30% and 40% and also partially replaced the FA with sand stone (crushed), concrete and marble waste. Concrete blocks of size 200 x 200 x 80 mm were fabricated. Water absorption test results on the concrete paver blocks were represented in

Fig. 2.12. Concrete waste specimens showed higher water absorption results whereas samples containing marble waste showed lowest values among the specimens.

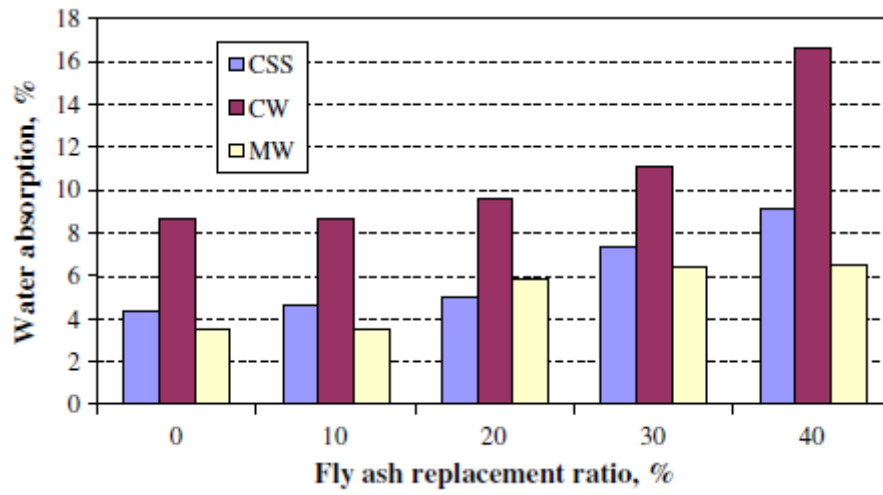


Fig. 2.12. Results of water absorption obtain by Uygunog et al. 2012.

## Chapter 3 Experimental Program

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### 3.1 Preliminary Testing

The preliminary testing comprises the testing of the materials to be used in casting of the samples. This included the tests on cement, fine aggregate, coarse aggregate, silica fume, fly ash, and metakaolin. Materials used were also examined for the mechanical as well as physical properties of in the casting work.

### 3.2 Materials and Properties

The different properties like soaking up of water, specific gravity and sieve size analysis of the cement, fine aggregate, coarse aggregate were performed in addition with silica fume, metakaolin, fly ash and crushed glass was investigated before using them in the casting so as to ensure any change in the test results due to these properties. The material and the results of their properties investigated are as shown below:

#### 3.2.1 Fine Aggregate

The graded sand having nominal size of aggregate of 4.75 mm was used as fine aggregate in the concrete. The fine aggregate were verified as per Indian Standard Specification BIS: 383-1970. The properties of the fine aggregate such as sieve size analysis are compared with those of standard recommendations as per BIS: 383-1970. The Physical properties and sieve analysis of fine aggregate is given below in Tables 3.1 and 3.2.

**Table 3.1.** Sieve analysis of fine aggregate.

S. No.	Nominal sieve size (mm)	Mass retained (grams)	Percentage retained (%)	Percentage passing (%)	Cumulative percentage retained (%)
1	4.75	27	2.7	97.5	2.6
1	2.36	106	10.6	86.6	13.3
2	1.18	160	16	69.9	29.3
3	600	148	14.8	55.5	44.1
4	300	192	19.2	35.3	63.3
5	150	278	27.8	8.9	91.1
6	PAN	89	8.9		
SUM		1000		$\Sigma\%$ Retained = 243.7	

$$\text{Fineness-Modulus} = 243.7/100 = 2.43$$

**Table 3.2.** Properties of fine aggregate.

<b>Properties of FA</b>	<b>Observed values</b>
Minimum size of aggregates	4.75
Specific gravity	2.63
Water absorption	0.82
Fineness modulus	2.43
Grade of sand	Grade II



**Fig. 3.1.** Fine aggregates

### **3.2.2 Coarse Aggregates**

The highest nominal size of CA used in paver block production is 12 mm and 4.75 mm retaining is used in study. The Physical properties of the used coarse-aggregate were tested and are given in Table.3.3.



**Fig. 3.2.** Coarse aggregates

**Table 3.3.** Coarse aggregate properties.

Property	Observed value
Specific Gravity	2.7
Net Soaking up of water	0.85
Fineness Modulus	6.26
Maximum size of aggregate	10mm
Water absorption	0.48%
Shape	Angular
Colour	Grey



**Fig. 3.3.** Sieve analysis apparatus

**Table 3.4.** Sieve-analysis of CAs.

Sr.no	IS Sieve	Mass Retained (gm)	Mass Retained (%)	Percentage passing	Cumulative retained (%)
1	20 mm	0	0	100	0
2	10 mm	4272	42.72	57.28	42.72
3	4.75	4456	44.56	12.72	87.28
4	2.36	998	9.98	2.74	97.26
5	1.18	243	2.43	0.31	99.69
6	600	26	0.26	.05	99.95
7	300	0	0	0	100
8	150	0	0	0	100
9	PAN	5	0.05	0	
Total		1000		$\Sigma$ % Retained =626.9	

Finesse modules = 6.26

### 3.2.3 Cement

Cement is the most important material to be used in the concrete because it is a best binder material. It is used to bind the sand and gravels together in the concrete it is very rear to use the cement on its own. There are three different grades of OPC are available in the market, namely 33 Grade, 43 Grade, 53 Grade depending on 28 days strength. In our study, OPC (JK Lakshmi cement) of 43 Grade cement is used. Table 3.5 shows the physical properties of cement. Cement used was fresh and free from lumps. Cement used in this study was stored because its properties deteriorate on contact with moisture. So, to prevent cement it is stored carefully.

**Table 3.5.** Properties of the cement.

<b>Name of the Property</b>	<b>Results</b>	<b>Recommended value (IS 8112:1986)</b>
Grade of Cement OPC	43	-
Specific Gravity	3.15	-
Initial-Setting Time (min)	130	300 (Max.)
Final-Setting Time (min)	265	600 (Max.)
Consistency of Standard Cement paste (%)	28	-
Compressive strength (N/mm <sup>2</sup> )		
7 days	38	33
28days	47.2	43

### 3.2.4 Silica fumes

In the study, silica fume is used for the preparation of concrete as a substitute of cement to study its usefulness for production of interlocking paver blocks. Silica fume was obtained from Haryana ceramics Pvt. Ltd, Ambala city, Haryana. The physical and chemical properties of silica fume as providing by the supplier are represented in Table 3.6 and Table 3.7, respectively. Due to tiny particle size, it acts as both pozzolanic material as well as micro fillers in concrete matrix.

**Table 3.6.** Physical properties of silica fume.

<b>Characteristics</b>	<b>Value</b>
Colour	Dark grey
Specific gravity	2.25

**Table 3.7.** Chemical composition of silica fume provided by the supplier.

SiO <sub>2</sub>	92.25%
MgO	1.5%
SO <sub>3</sub>	1.1%
H <sub>2</sub> O	0.4%
K <sub>2</sub> O	2.25%
Na <sub>2</sub> O	1.4%
CaO	0.35%
Si	0.5%
Cl	0.06%
Fe <sub>2</sub> O <sub>3</sub>	2%



**Fig. 3.4.** Silica Fumes

### **3.2.5 Metakaolin**

Metakaolin is produced when pure or refined kaolinite clay is calcinated at temperature between 650° C to 850° C, then the obtained material is grinded to achieve the fineness of 700-900 m<sup>2</sup>/kg. It is a very good pozzolanic material and can be used as the substitute of cement in the mix. Due to its tiny particle size metakaolin also functions as a micro filler in concrete matrix. The physical and chemical-properties of metakaolin are represented in Table 3.9 respectively.

**Table 3.8.** Comparison of chemical composition of metakaolin and cement.

Chemical composition	Cement%	Metakaolin%
Silica (SiO <sub>2</sub> )	32	53.3
Alumina Al <sub>2</sub> O <sub>3</sub>	5.	39.3
Calcium oxide CaO	36	0.40
Ferric oxide calcium oxide (Fe <sub>2</sub> O <sub>3</sub> )	4.5	4.29
Magnesium oxide (MgO)	1.24	0.07
Potassium oxide (K <sub>2</sub> O)	0.4.9	0.51
Sulphuric anhydride (SO <sub>4</sub> )	1.9	0.22
LOI	1.5	0.70
Specific gravity	3.14	2.49
Physical form	Fine powder	Powder
Color	Grey	Off white

### 3.2.6 Fly ash

Fly ash is obtained from Guru Nanak Dev Thermal Plant, Bathinda, Punjab. The properties of fly ash is represented in the Table 3.10 and Table 3.11, respectively.

**Table 3.9.** Composition of fly ash.

Chemical composition	Fly ash, %
Silica (SiO <sub>2</sub> )	35.91
Alumina Al <sub>2</sub> O <sub>3</sub>	16.02
Calcium oxide CaO	14.43
Ferric oxide calcium oxide (Fe <sub>2</sub> O <sub>3</sub> )	12.34

**Table 3.10.** Physical properties of fly ash used.

Color	Whitish grey
Bulk density (g/cm <sup>3</sup> )	0.994
Specific gravity	2.288
Moisture	3.14
Average size of particles (μm)	6.92



Fig. 3.5. Metakaolin



Fig. 3.6. Fly ash

**Table 3.11.** Comparison of chemical composition of fly ash, metakaolin, silica fumes with cement.

Chemical composition	Cement%	Metakaolin, %	Fly ash, %	Silica fumes, %
Silica (SiO <sub>2</sub> )	32	53.3	35.91	92.5%
Alumina (Al <sub>2</sub> O <sub>3</sub> )	5	39.3	16.02	-
Calcium oxide (CaO)	36	0.40	14.43	0.35%
Ferric oxide calcium oxide (Fe <sub>2</sub> O <sub>3</sub> )	4.5	4.29	12.34	2%
Magnesium oxide (MgO)	1.24	0.07	9.09	1.5%
Potassium oxide (K <sub>2</sub> O)	0.4.9	0.51	1.28	2.25%

### 3.2.7 Glass cullet

Glass cullet is a waste material and can be obtained from many sources. The glass in this study is obtained from Firozabad, Uttar Pradesh. Then it is grinded to same size as construction sand it shows the same properties as the sand. The chemical composition of both glass cullet and

sand is given in the Table 3.8. Properties of both the materials are approximately same, therefore sand can be replaced with glass cullet in concrete.

**Table 3.12.** Comparison of chemical properties of glass cullet and natural sand.

<b>Composition</b>	<b>Natural sand (%)</b>	<b>Glass cullet (%)</b>
Silica, SiO <sub>2</sub>	81.98	78.13
Sodium oxide, Na <sub>2</sub> O	1.5	14.5
Lime, CaO	2.8	11.21
Alumina, Al <sub>2</sub> O <sub>3</sub>	9.88	2.6
Magnesia, MgO	5.2	1.9
Potassium oxide, K <sub>2</sub> O	1.32	0.26
Ferrous oxide, Fe <sub>2</sub> O <sub>3</sub>	1.18	0.36
Sulphur trioxide, SO <sub>3</sub>	Nil	0.11
Chromium oxide, Cr <sub>2</sub> O <sub>3</sub>	Nil	0.02
All other oxides	Nil	Nil



**Fig. 3.7.** Glass cullet

### 3.3 Preparation of Materials for Casting

#### 3.3.1 Mix-Design as per IS 10262:2009

The concrete mix-design is conceded for a particular strength of concrete to achieve acceptable amount of workability so that the mix can be easily transported, placed and compacted. The concrete mix-design as per Indian Standards IS 10262-2009 is done for the casting of the specimens for different tests to be performed. The concrete mix is done for M35 grade of concrete. The preliminary data of the constituent materials required for the mix design of concrete is found out as stated above. The amounts of the material required per-cubic meter volume of concrete are found out and the quantities per batch of the concrete were calculated by multiplying the calculated data with the batch volume. And the different materials quantities are calculated. The quantities of the materials required per cubic meter of concrete are as given below in the Table:

Mix Design Data: M35

Characteristic compressive strength at 28 Days = 35 N/mm<sup>2</sup>

Maximum size of aggregate = 12 mm

Type of Exposure = Mild Concrete

**Table 3.13.** Mix proportion of M35 grade of concrete.

Name of the material	Quantity (Kg/m <sup>3</sup> )
Cement	404
Fine aggregate	721.5
Coarse aggregate	1082 Kg
Water	181.82 Kg
w/c ratio	0.45

#### 3.3.2 Mix composition

Control mixtures with constant amount of cement content, fine and CA were made and paver block is caste. Curing of the blocks is done for 28 days and maximum 28 days strength of 53.2 MPa achieved. To find out optimum content of fly ash, metakaolin, silica fumes and glass without compromising this strength different attempt were made which are described below:

Attempt First: In the mix proportion of the different mixes, the content of fine-aggregate was varied with fine glass in proportion of 0%, 5%, 10%, 15% and 20%. replacement level without any pre-treatment and at water cement ratio of.0.45, then it then mechanical properties of paver blocks were observed.

Attempt Second: In the mix proportion of the different mixes, the cement content was varied with fly ash, metakaolin and silica fumes in proportion of 0%, 5%, 10%, 15% and 20% respectively and at w/c ratio 0.45, then it then mechanical properties of paver blocks were observed.

After the testing of all the specimens for replacement of both cement and sand, optimum percentage at which the specimen gives the best result is used to for the casting and testing of another batch of the paver blocks.

Attempt Third: The proportions at which paver blocks gives the best results are used to caste paver blocks in which replacement was made by adding fly ash, metakaolin and silica fumes respectively to cement. Also, fine aggerates were replaced by fine glass at w/c ratio 0.45, then it then mechanical properties of paver blocks were observed.

**Table 3.14.** Concrete mix proportions for glass cullet.

Mix	Cement, kg/m <sup>3</sup>	Fine Aggregates, kg/m <sup>3</sup>	Coarse Aggregates, kg/m <sup>3</sup>	Water (litres)	Glass, kg/m <sup>3</sup>
Control mix	404	721.5	1082	181.82	0
G <sub>5</sub>	404	685.40	1082	181.82	36.07
G <sub>10</sub>	404	649.35	1082	181.82	72.15
G <sub>15</sub>	404	613.27	1082	181.82	108.22
G <sub>20</sub>	404	577.20	1082	181.82	144.3

**Table 3.15.** Concrete mix proportions for fly ash and glass cullet.

Mix no.	Cement kg/m <sup>3</sup>	Fine Aggregates kg/m <sup>3</sup>	Coarse Aggregates kg/m <sup>3</sup>	Water (liters)	Fly ash kg/m <sup>3</sup>	Glass, kg/m <sup>3</sup>
Control mix	404	721.5	1082	181.82	0	0
FA <sub>5</sub>	383.8	721.5	1082	181.82	20.2	0
FA <sub>10</sub>	363.6	721.5	1082	181.82	40.4	0
FA <sub>15</sub>	343.4	721.5	1082	181.82	60.6	0
FA <sub>20</sub>	323.2	721.5	1082	181.82	80.8	0
FA <sub>15</sub> G <sub>10</sub>	343.4	649.35	721.5	181.82	60.6	72.15

**Table 3.16.** Concrete mix proportions for silica fumes and glass.

Mix no.	Cement (kg/m <sup>3</sup> )	Fine aggregates (kg/m <sup>3</sup> )	Coarse aggregates (kg/m <sup>3</sup> )	Water (liters)	Silica fumes (kg/m <sup>3</sup> )	Glass (kg/m <sup>3</sup> )
Control mix	404	721.5	1082	181.82	0	0
SF <sub>5</sub>	383.8	721.5	1082	181.82	20.2	0
SF <sub>10</sub>	363.6	721.5	1082	181.82	40.4	0
SF <sub>5</sub>	343.4	721.5	1082	181.82	60.6	0
SF <sub>20</sub>	323.2	721.5	1082	181.82	80.8	0
SF <sub>15</sub> G <sub>10</sub>	343.4	649.35	721.5	181.82	60.6	72.15

**Table 3.17.** Concrete mix proportions for metakaolin and glass.

Mix no.	Cement (kg/m <sup>3</sup> )	Fine aggregates (kg/m <sup>3</sup> )	Coarse aggregates (kg/m <sup>3</sup> )	Water (liters)	metakaolin (kg/m <sup>3</sup> )	Glass (kg/m <sup>3</sup> )
Control mix	404	721.5	1082	181.82	0	0
MK <sub>5</sub>	383.8	721.5	1082	181.82	20.2	0
MK <sub>10</sub>	363.6	721.5	1082	181.82	40.4	0
MK <sub>15</sub>	343.4	721.5	1082	181.82	60.6	0
MK <sub>20</sub>	323.2	721.5	1082	181.82	80.8	0
MK <sub>15</sub> G <sub>10</sub>	343.4	649.35	721.5	181.82	60.6	72.15

### 3.3.3 Testing program

Shape of the specimens are chosen as per the specifications given in IS: 15658 (2006). The different tests performed on the casted specimens and standards followed for the testing procedure are as given below in Tables 3.18 and 3.19.

**Table 3.18.** Description of specimens.

Name of test	Size of specimen	Shape of specimen	Type of specimen	No of paver blocks for each test
Compressive strength test	200 x 160 x 60	Type-B (Dumbbell shape)	Block	4
Flexural strength test	200 x 160 x 60	Type-B	Block	4
Water absorption test	200 x 160 x 60	Type-B	Block	3

**Table 3.19.** Specimen Id for different mix proportions of concrete.

Specimen Id	Percentage of fly ash (FA)	Percentage of Metakaolin (MK)	Percentage of Silica Fumes (SF)	Percentage of Glass (G)
FA <sub>5</sub>	5	0	0	0
FA <sub>10</sub>	10	0	0	0
FA <sub>15</sub>	15	0	0	0
FA <sub>20</sub>	20	0	0	0
MK <sub>5</sub>	0	5	0	0
MK <sub>10</sub>	0	10	0	0
MK <sub>15</sub>	0	15	0	0
MK <sub>20</sub>	0	20	0	0
SF <sub>5</sub>	0	0	5	0
SF <sub>10</sub>	0	0	10	0
SF <sub>15</sub>	0	0	15	0
SF <sub>20</sub>	0	0	20	0
G <sub>5</sub>	0	0	0	5
G <sub>10</sub>	0	0	0	10
G <sub>15</sub>	0	0	0	15
G <sub>20</sub>	0	0	0	20
FA <sub>15</sub> G <sub>10</sub>	15	0	0	10
MK <sub>15</sub> G <sub>10</sub>	0	15	0	10
SF <sub>15</sub> G <sub>10</sub>	0	0	15	10

### 3.4 Casting of paver blocks

In this study, paver blocks of size 200 x 160 x 60 mm were casted. The quantities of the different materials like CA, sand, cement, silica fume, fly ash, metakaolin and fine glass were weighted independently. And then all are put in the mixer and the dry mixing is done for 1 to 2 minutes. The resulting mix should be uniform/even in appearance. After that the 50 to 70% of the water is added to the mixture and further mixing of material for 2 to 3 minutes is done and then the remaining water is added in the mix. Further mixing is performed 2 to 3 minutes. Before pouring the prepared concrete in the moulds, dressing of moulds with oil is done properly and then the fresh concrete mix is filled in the moulds. After filling the mix, the moulds are put on the vibrating machines to remove the voids and to get maximum compaction. After 24 hrs the specimens are taken out of the moulds and the specimens are tested after the curing period of tank 7 days and 28 days compressive test and flexural strength test.



(a) Moulds



(b) Wet specimen

**Fig. 3.8.** Casting of concrete paver blocks

### 3.5 Testing of paver blocks

#### 3.5.1 Water absorption test

The specimen to be tested for water absorption shall be completely immersed in room temperature for 24 hrs. After 24 hrs specimen is removed from the water and is put on the wire mesh for 1 minute to drain. Damp cloth should be used to remove the visible water. Then the specimen is immediately weighed. After saturation, ventilated oven at  $107 \pm 7^\circ\text{C}$  is used for the drying of specimen for minimum 24 hrs. Two successive readings of the specimen after every 2 hrs were taken, the rise of loss should not be greater than 0.2% of the previous found mass of the specimen.

$$w(\%) = \frac{w_w - w_d}{w_d} \times 100$$

where  $w_w$  is the weight of saturated sample and  $w_d$  is the weight of dry sample

#### 3.5.2 Compression test

The compressive strength of concrete is tested on the compression testing machine (CTM) having load carrying capacity 5000 kN and it gives us the maximum compressive load taken by concrete block before failure. The compressive strength is calculated by dividing the maximum compressive load with average cross section area. Paver block sample of size 200 x 160 x 60 mm was casted and tested for compressive-strength as per Indian standard specifications of IS: 516-1959. On the day of the testing the sample are carried from the curing tank and kept outside for about 30 to 60 minutes. Then the samples are placed in between the

two plates of Compression testing machine (CTM). Before placement of samples the plates should be cleaned thoroughly so that the load can be distributed evenly. Then the test is done at the loading rate of 5 kN/s as per IS: 516 -1959. Then the reading at which the sample failed is written.



**Fig. 3.9.** Compression testing machine

### 3.5.3 Flexural Test

Indian standard (IS.516) specifications are used for the testing procedure of flexural strength of paver blocks. The loading shall be exerted from the top of the paver block. The block is tested as a beam. Two-point loading should be applied for finding the strength. The block is loaded from top at the centre of concrete paver block and supported by one roller on both sides. The loading should be raised continuously at the rate of 6 kN/min without applying any shock to the specimen. Loading should be applied until the block fails and flexural strength is calculated using the Eq. (3)

$$F_a = \frac{3PL}{2bd^2} \quad (3.3)$$

Where,  $F_a$  is the flexural strength of the specimen

$P$  is the maximum load

$L$  is the distance between rollers and centre line

$b$  is the average width of block

$d$  is the average thickness



**Fig. 3.10.** Flexural test setup

#### **3.5.4 Scanning electron microscope (SEM)**

In order to study the elements of the concrete at the microscopic level, SEM is conducted. This test is conducted to analyse composition (natural-sand, CSH gel, calcium hydroxide, cement and materials used for the substitute of cement and sand) and morphology of the concrete at different magnification. It is conducted at 5 different magnification level for having clear idea of size particle in the concrete matrix. This test is done with the help of Energy Dispersive Spectroscopy instrument. In this study, five types of samples are tested for determining the microscopic properties of the concrete contain fly ash, metakaolin and silica fumes as the partial substitution of cement and glass as the partial substitution of sand. Table 3.16 represents the proportions of the materials in the samples. The thickness of the sample was approximately 2-3 mm. To increase the signal of the image, coating of gold has been done on the sample which can conduct the electricity through it.

**Table 3.20.** Proportions of materials in the concrete samples to be tested.

<b>Specimen Id</b>	<b>Percentage of cement replacement</b>	<b>Percentage of sand replacement</b>
Sample-1	Fly ash 15%	Glass 10%
Sample-2	Silica fumes 15	Glass 10%
Sample-3	Metakaolin 15%	Glass 10%
Sample-4	-	Glass 10%
Sample-5	Fly ash 15%	-

## Chapter 4 Result and Discussion

### 4.1 General

This chapter presents the hardened properties of the paver blocks. Hardened property of concrete paver blocks is determined aft. Different tests such as flexural test, compressive test is performed on the blocks. Water absorption is also performed. These tests are performed as per the specifications of IS: 15658 (2006). Properties determined from conducted tests are water absorption tests, compressive strength and flexural strength characteristics are explained in the following sections:

### 4.2 Water Absorption

The water absorption of the ICPB is carried out as per the specifications of IS: 15658: 2006 (clause6.2.4). The water absorption of single ICPB should not be less than 7% or should not be more than 6% by mass i.e., average of three block specimen. The water absorption of all the individual units is well below 7%. After saturation and drying of specimen for 24 hrs each no block unit shows an increase of loss should be less than 0.2 percent as per IS: 15658 (2006). Table 4.1 to 4.4 shows the test results for water absorption test.

**Table 4.1.** Water absorption test of paver blocks when fly ash is added to the specimen.

% replacement of cement with Fly ash	Sample no.	Water absorption percentage	Average water absorption percentage
0	1	1.36	1.50
	2	1.64	
	3	1.50	
5	1	1.69	1.86
	2	1.89	
	3	2.00	
10	1	2.20	2.31
	2	2.45	
	3	2.28	
15	1	2.61	2.56
	2	2.39	
	3	2.70	
20	1	3.40	3.20
	2	3.10	
	3	3.11	

**Table 4.2.** Water absorption test of paver blocks when sand is replaced with fine glass.

<b>% replacement of cement with glass</b>	<b>Sample no.</b>	<b>Water absorption percentage</b>	<b>Average water absorption percentage</b>
0	1	1.36	1.50
	2	1.64	
	3	1.50	
5	1	2.01	2.26
	2	2.40	
	3	2.38	
10	1	3.94	3.84
	2	3.65	
	3	3.96	
15	1	4.20	4.29
	2	4.31	
	3	4.37	
20	1	4.53	4.57
	2	4.68	
	3	4.50	

**Table 4.3.** Water absorption of paver blocks when cement is replaced with silica fumes.

<b>% replacement of cement with silica fumes</b>	<b>Sample no.</b>	<b>Water absorption percentage</b>	<b>Average water absorption, %</b>
0	1	1.36	1.50
	2	1.64	
	3	1.50	
5	1	2.00	2.15
	2	2.10	
	3	2.35	
10	1	2.91	2.82
	2	2.86	
	3	2.70	
15	1	3.10	2.93
	2	2.99	
	3	2.81	
20	1	3.40	3.21
	2	3.19	
	3	3.04	

**Table 4.4.** Water absorption test of paver blocks when cement is replaced with metakaolin.

% replacement of metakaolin	Sample no.	Water absorption, %	Average water absorption, %
0	1	1.36	1.50
	2	1.64	
	3	1.50	
5	1	2.49	2.45
	2	2.56	
	3	2.30	
10	1	2.96	2.97
	2	3.16	
	3	2.80	
15	1	3.67	3.82
	2	3.94	
	3	3.86	
20	1	3.99	4.20
	2	4.47	
	3	4.19	

### 4.3 Compressive strength

Average strength of the block specimen when cement in the mix is replaced by silica fumes by weight are found out and the outcomes are demonstrated in tables below. The compression testing and failure of the sample is shown in the Fig. 4.1.



(a) Cracks during testing

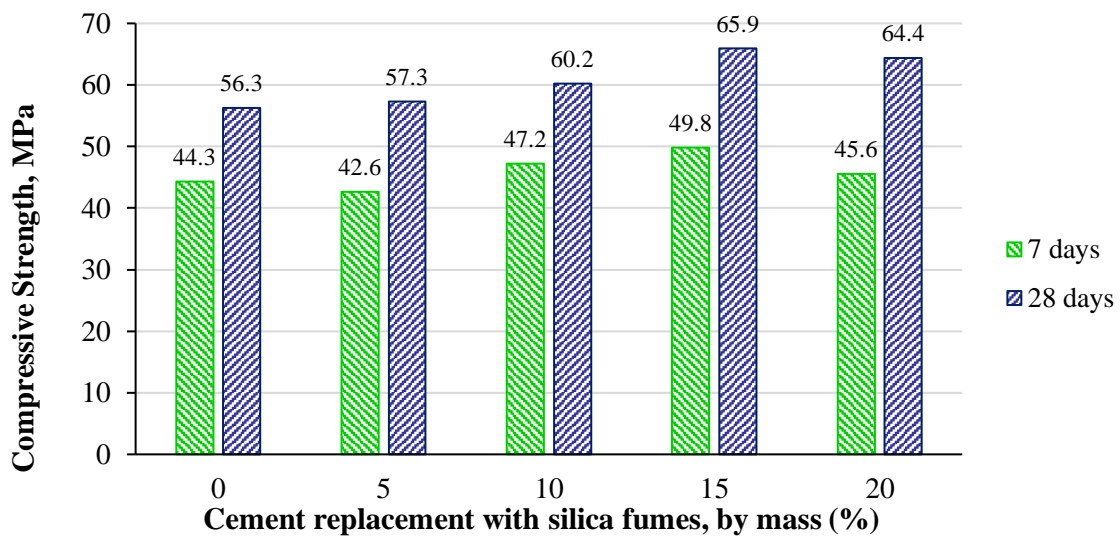
(b) After failure

**Fig. 4.1.** Compression testing of the concrete block specimen and failure of the block specimen

#### 4.3.1 Partial replacement of cement with silica fumes

Table 4.5 and Fig. 4.2 represents the mean compressive strength of paver blocks. It has been observed that when silica fumes are added in the concrete by replacing cement in the mix. All

the concrete mixes including control mix achieved their target strength of 35 MPa at 28 days. Table.4.1 presents all concrete specimens achieve the average compressive strength of .56.3 for OPC and 57.55, 60.2, 65.93, 60.4 when silica fumes is added in the concrete at 5%, 10%, 15% and 20% respectively. After, the end of curing period of 28 days the strength of block specimens when cement is replaced with silica fumes at 5% is.56.3 MPa. The increment in strength of block specimen is 2.2% when compared with the controlled specimen. At 10%, 15% and 20% replacement of silica fumes there is an increment in compressive strength of 6.9%, 17.1%,14.3% respectively. Cement when replaced with SF at 15% exhibit higher strength, when compared to other mix. But SF at 20% replacement strength decreases by 9.9% when compared with SF at 15%. So, SF 15% is the best proportion for add in the cement.



**Fig. 4.2.** Compressive strength of blocks with different proportion of silica fumes

**Table 4.5.** Compressive strength of block with different proportion of silica fumes.

Age of test	Compressive strength (MPa)									
	Control mix		SF <sub>5</sub>		SF <sub>10</sub>		SF <sub>15</sub>		SF <sub>20</sub>	
7 Days	43.8	44.3	42.3	42.6	46.80	47.4	49.90	49.8	44.90	45.6
	45.6		45.6		45.90		49.60		46.30	
	42.9		41.2		47.80		48.20		44.30	
	45.00		41.3		48.90		51.60		46.60	
28 Days	52.2	53.2	58.30	57.3	61.2	60.2	66.30	65.9	64.90	64.4
	52.6		55.60		59.6		65.40		63.50	
	53.4		57.4		59.3		67.30		65.90	
	54.6		57.9		60.7		66.20		63.30	
%, increase	-		2.2*		6.9		17.1		14.3	

\*Percentage increase w.r.t control specimens.

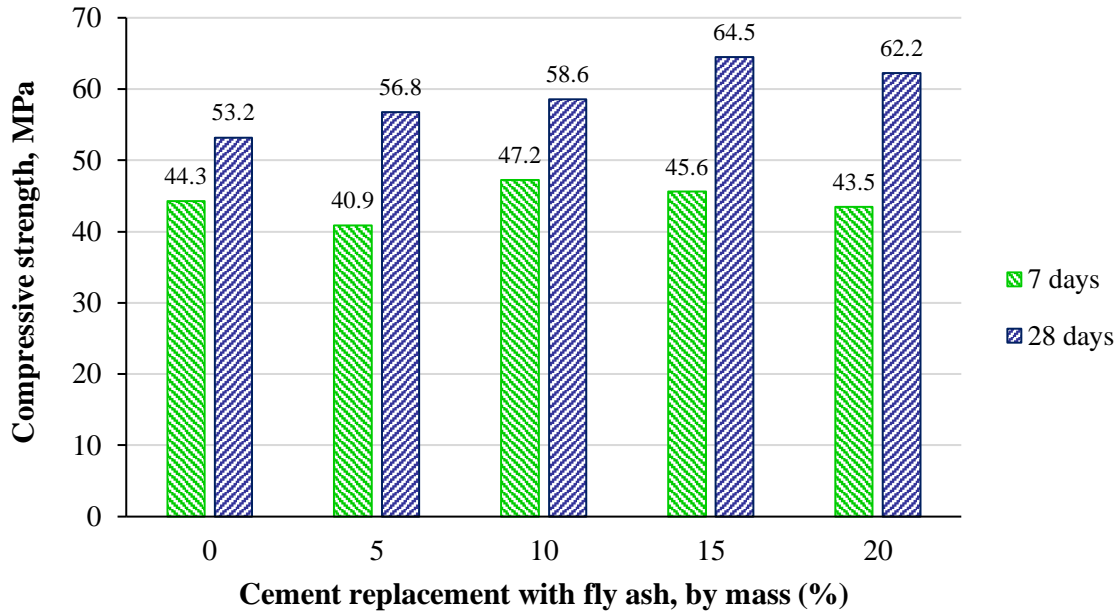
### 4.3.2 Partial replacement of cement with fly ash

Table 4.6 and Fig. 4.3 represents the average compressive strength of block specimen. Average compressive strength of paver block specimen when cement is replaced with fly ash varied between 52 to 62 MPa. The average compressive strength of block specimen when replaced with 5%,10%,15%,20% fly ash for 7 days and 28 days is 45.8 and 59.4 MPa which is more than the control mix specimen. All concrete mix including control mix achieved their target mean strength of 35 MPa at curing period of 28 days. After 28 days, there is rise in compressive strength when cement is replaced with 5% fly ash there is a rise of 1% compressive strength when compared with the controlled specimen. At 10%,15%, 20% fly ash content in the mix there is an increment in compressive strength of 4.08%, 14.6% and 10.4% respectively. Cement when replaced with fly ash at 15% exhibit higher strength as compared to other mix. At 20% fly ash in the mix, the strength of paver block decreases by 11.43% when compared with fly ash at 15%. So, fly ash at 15% in the concrete is the best proportion to be add in the cement as per the results.

**Table 4.6.** Compressive strength (MPa) of paver block with different proportion of fly ash.

Age of test	Compressive strength (MPa)									
	Control mix		FA <sub>5</sub>		FA <sub>10</sub>		FA <sub>15</sub>		FA <sub>20</sub>	
7 Days	43.8	44.3	41.30	40.9	45.80	47.2	44.70	45.6	43.80	43.5
	45.6		45.60		49.60		44.60		45.60	
	42.9		42.20		46.60		49.70		40.90	
	45.00		42.60		49.60		45.60		43.70	
28 Days	52.2	53.3	58.60	56.8	59.60	58.6	64.45	64.5	59.6	62.20
	52.6		57.60		57.60		61.50		63.4	
	53.4		54.20		58.01		67.50		61.2	
	54.6		56.80		59.19		64.50		64.60	
%, increase	-		1*		4.08		14.6		10.4	

\*Percentage increase w.r.t control specimens.



**Fig. 4.3.** Compressive strength of blocks with different proportion of fly ash

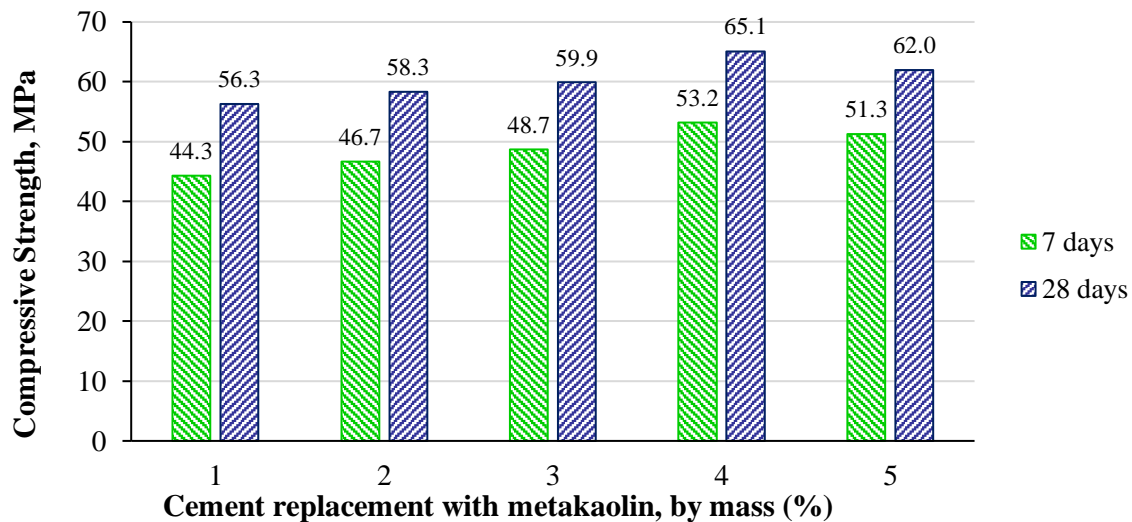
#### 4.3.3 Compressive strength of blocks with metakaolin

Table 4.7 and Fig. 4.4 represents the average compressive strength of paver block specimen after curing period of 7 days and 28 days. The average compressive-strength of block specimen when cement is replaced with metakaolin varied between 55.83 to 65.13 MPa. Average compressive strength of paver blocks when replaced with 5%, 10%, 15% and 20% metakaolin is 58.3, 59.9, 65.13 and 62.01 respectively. All the concrete mix including control mix achieved the compressive strength higher than target strength, i.e., 35 MPa at 28 days. After 28 days, there is rise in compressive strength when 5% metakaolin by weight is used in place of cement. There is an increment of 2.6% compressive strength when compared with the controlled specimen. At 10%, 15% and 20% addition of metakaolin there is a rise in compressive strength of 6.3%, 15.6% and 10.1%, respectively. When the 15% cement is replaced with metakaolin achieved higher strength as compared to other mix. But concrete at 20% metakaolin in the mix, the strength of paver block decreases by 6.9% when compared with metakaolin at 15%. So, 15% metakaolin is considered as the best proportion.

**Table 4.7.** Compressive strength of paver block with different proportion of metakaolin.

Age of test	Compressive strength (MPa)									
	Control mix		MK <sub>20</sub>		MK <sub>10</sub>		MK <sub>15</sub>		MK <sub>20</sub>	
7 Days	43.8	44.30	45.60	46.70	47.60	48.70	52.10	53.20	52.10	51.30
	45.6		47.20		49.70		54.20		50.00	
	42.9		46.60		48.60		54.20		50.02	
	45.00		47.00		49.00		52.30		53.20	
28 Days	52.2	53.20	56.67	58.30	61.02	59.90	64.52	65.10	61.32	62.00
	52.6		60.65		60.90		66.25		57.60	
	53.4		59.45		57.51		64.25		63.59	
	54.6		56.63		60.71		65.63		65.49	
%, increase			2.6*		6.3		15.6		10.1	

\*Percentage increase w.r.t control specimens.



**Fig. 4.4.** Compressive strength of blocks with different proportion of metakaolin

#### 4.3.4 Partial replacement of sand with glass cullet

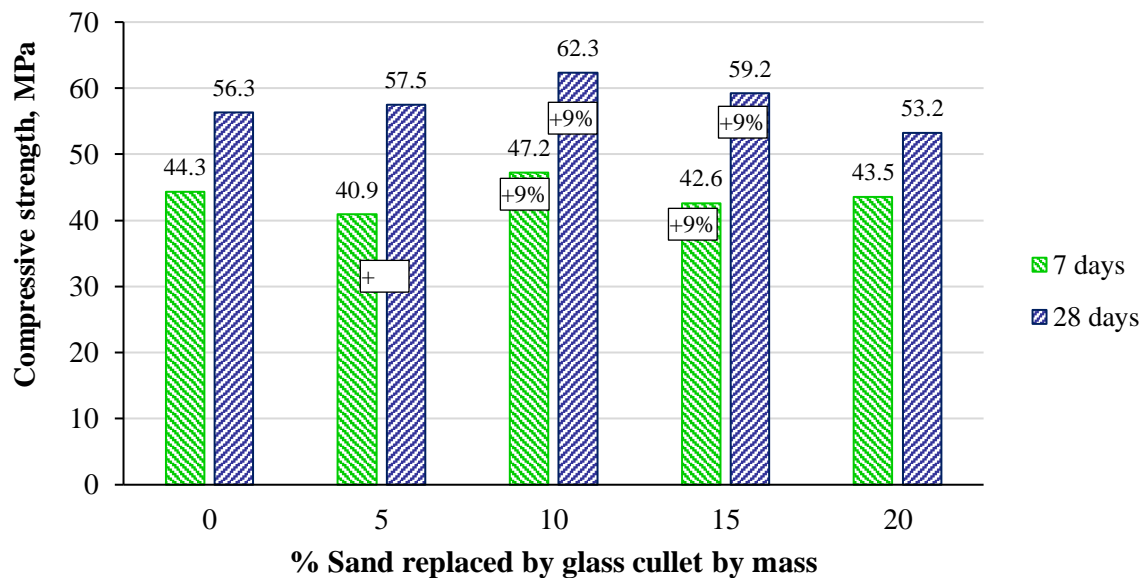
Table 4.8 and Fig. 4.5 represents the average compressive strength of block specimen at the end of curing of 7 days and 28 days. Average compressive-strength of block specimen when FA are replaced with glass varied between 53.2 to 62.35 MPa for different percentage of glass. The average compressive strength of block specimen when sand is replaced with glass at 5%, 10%, 15% and 20% is 57.55%, 58.6%, 64.52% and 58.23% respectively. After 28 days, there is rise in compressive strength of paver blocks when sand is replaced with 5% glass. There is an increment of 2.06% compressive-strength when compared with the controlled specimen. At 10% and 15% replacement of sand with glass there is a rise in compressive-strength of 10.56% and 5% respectively. When sand is replaced with 20% glass, reduction in strength of 5.6% of

the specimen is observed. Sand when replaced with glass at 10% exhibit higher strength as compared to other mix. But glass at 15% and 20% in concrete decrease the strength of paver blocks by 5.56% and 16.16 respectively when compared with glass at 10%. So, paver blocks with glass at 10% is the best proportion for add in the cement mix.

**Table 4.8.** Compressive strength of paver block with different proportion of glass cullet.

Age of test	Compressive strength (MPa)									
	Control mix		G <sub>5</sub>		G <sub>10</sub>		G <sub>15</sub>		G <sub>20</sub>	
7 Days	43.8	44.3	39.90	40.90	46.6	47.20	42.40	43.50	42.00	42.65
	45.6		39.80		48.9		41.10		39.65	
	42.9		40.90		47.4		44.6		43.50	
	45.00		42.80		45.9		45.9		45.45	
28 Days	52.2	53.2	54.7	57.50	61.50	62.30	57.60	59.20	51.30	53.20
	52.6		56.9		63.21		58.90		52.30	
	53.4		58.5		60.50		58.59		55.60	
	54.6		59.90		63.99		61.71		53.60	
%, increase			2.06*		10.56		5		0	

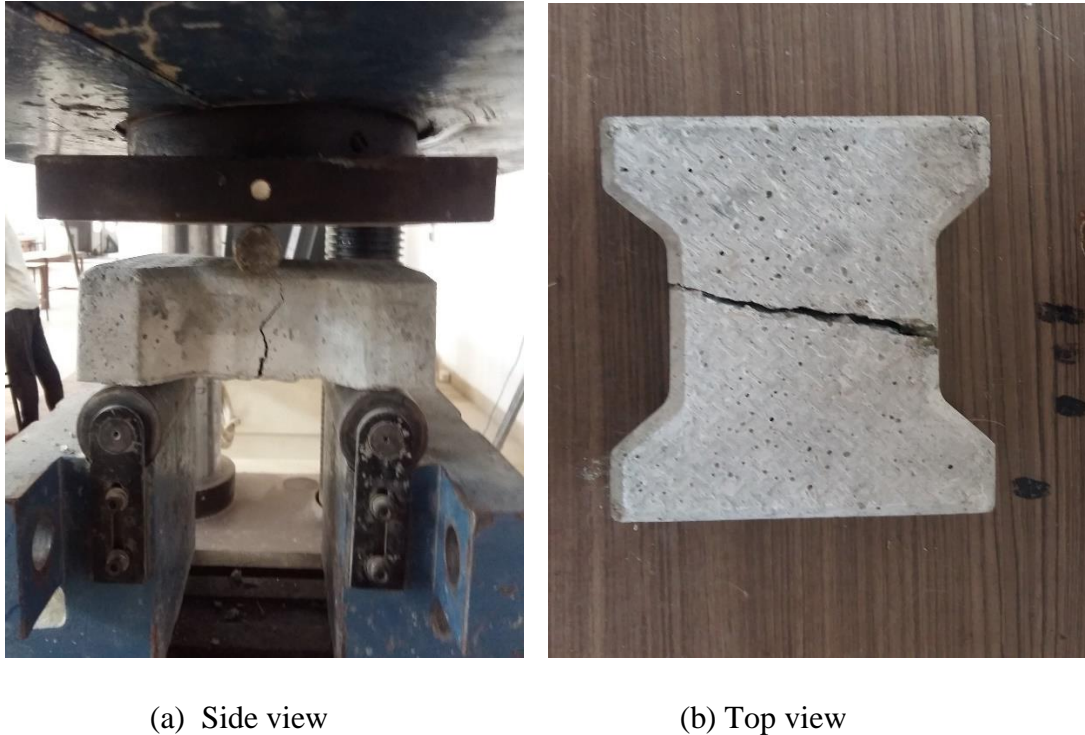
\*Percentage increase w.r.t control specimens.



**Fig. 4.5.** Compressive strength of blocks with different proportion of glass replaced with sand.

#### 4.4 Flexural characteristics

Flexural strength of the block units is tested as per IS: 15658 (2006). The average flexural strength of the concrete when cement and sand in mix is replaced by different materials by weight are found out and the outcomes are denoted in tables below. The flexural testing and failure of the sample is shown in the Fig. 4.6.



**Fig. 4.6.** Flexural testing of the concrete block specimen and failure of the block specimen

##### 4.4.1 Flexural strength of blocks having partial replacement of cement with fly ash

The flexural strength of paver block is tested at the end of curing period of 7 and 28 days. It is detected that the strength of paver blocks goes on increases up to 10% then it slightly decreases as the fly ash goes on increases in the mix as the cementitious material. All the specimens show high strength of paver blocks then the control specimen. The increase in flexural strength is 3.6 % when 5% fly ash is added in the mix as cementitious material. But it appears, the flexural strength of paver blocks goes on decreasing when fly ash goes on increasing from 10% to 20% in the mix. Outcome for flexural strength of paver block specimens FA<sub>0</sub>, FA<sub>5</sub>, FA<sub>10</sub>, FA<sub>15</sub> and FA<sub>20</sub> at 7 days and 28 days are presented in the Table 4.9.

**Table 4.9.** Flexural strength (MPa) of block specimen when cement is replaced with fly ash.

Age of test	Flexural strength of control mix		Flexural strength (MPa)							
			FA <sub>5</sub>		FA <sub>10</sub>		FA <sub>15</sub>		FA <sub>20</sub>	
7 Days	2.36	2.38	1.40	1.70	2.10	2.00	1.94	2.09	1.9	2.12
	2.30		1.50		2.0		2.00		2.00	
	2.48		1.90		2.10		2.20		2.25	
	2.40		2.00		1.9		2.25		2.40	
28 Days	2.76	2.72	2.90	2.85	2.65	2.87	2.75	2.79	2.86	2.74
	2.68		2.80		2.91		2.65		2.75	
	2.86		2.80		2.43		2.80		2.46	
	2.40		2.90		3.49		2.96		2.89	
%, increase			3.67*		5.51		2.57		0.75	

\*Percentage increase w.r.t control specimens.

#### 4.4.2 Flexural strength of blocks having partial replacement of cement with metakaolin

The flexural strength of paver block is tested at the end of curing period, i.e. after 7 days and 28 days. It is noticed that the flexural strength of paver blocks goes on increases as the percentage of metakaolin goes on increases in the mix from 5% to 15% then the strength slightly decreases for 20% as compared to 15%. All the specimens show high flexural strength of paver blocks then the control specimen. It is observed that there is an increment in the strength of 18.30% when 5% metakaolin is added in the mix as cementitious material. At 10%,15, and 20% there is an increase of 26.80%, 32.72% and 19.10% respectively. Results for flexural strength of paver blocks MC<sub>0</sub>, MC<sub>5</sub>, MC<sub>10</sub>, MC<sub>15</sub> and MC<sub>20</sub> at 7 days and 28 days are presented in the Table 4.10 and Fig. 4.7.

**Table 4.10.** Flexural strength (MPa) of paver blocks when cement is replaced with metakaolin.

Age of test	Flexural Strength (MPa)									
	Control mix		MK <sub>5</sub>		MK <sub>10</sub>		MK <sub>15</sub>		MK <sub>20</sub>	
7 Days	2.36	2.38	2.16	2.20	2.85	2.69	2.73	2.81	2.73	2.71
	2.30		2.17		2.71		2.85		2.84	
	2.48		2.24		2.59		2.64		2.67	
	2.40		2.23		2.61		3.00		2.60	
28 Days	2.76	2.74	3.20	3.22	3.39	3.45	3.59	3.61	3.12	3.24
	2.68		3.45		3.56		3.70		3.31	
	2.86		3.10		3.30		3.51		3.01	
	2.40		3.13		3.55		3.64		3.52	
%, increase			18.30*		26.80		32.70		19.10	

\*Percentage increase w.r.t control specimens.

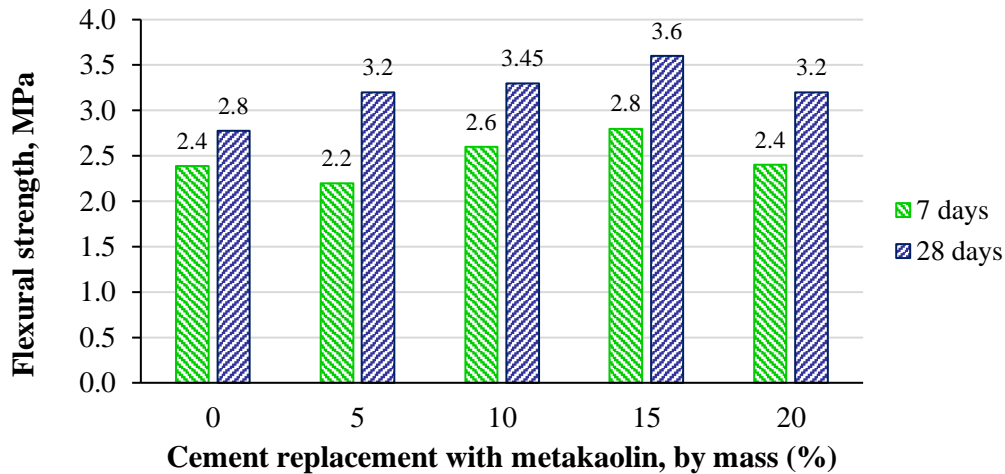


Fig. 4.7. Flexural strength of blocks with different proportion of metakaolin

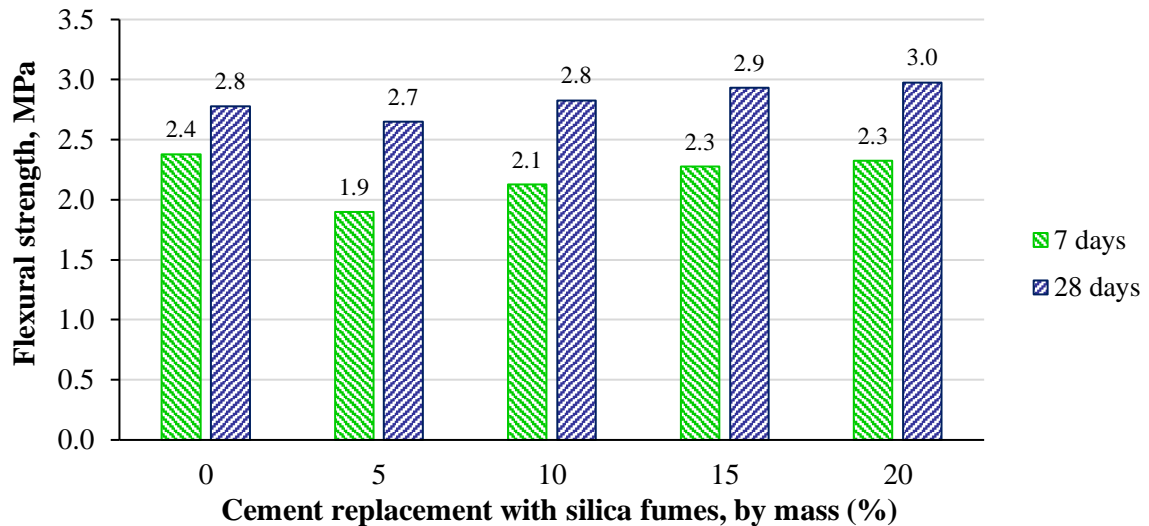
#### 4.4.3 Flexural strength of blocks having partial replacement of cement with silica fumes.

The flexural strength of paver block is examined at the end of curing period i.e. 7 days and 28 days. It is noticed that the strength of block specimens goes on increased as the percentage of silica fumes goes on increases in the mix as the cementitious material. Silica fumes at 5% in the mix shows less flexural strength of paver blocks then the control specimen. There is an increase in the strength of block units when percentage of silica fumes is increased from 10% to 20% then the control specimen. The percentage decrease in flexural strength is 2.50% when 5% silica fumes is added in the mix as cementitious material. Percentage rise in the strength for 10%, 15% and 20% is 3.67%, 7.72% and 9.19% respectively. Observations of flexural strength of block specimen SF<sub>0</sub>, SF<sub>5</sub>, SF<sub>10</sub>, SF<sub>15</sub> and SF<sub>20</sub> at 7 days and 28 days are presented in the Table 4.11 and Fig. 4.8.

Table 4.11. Flexural strength of paver blocks when cement is replaced with silica fumes.

Age of test	Flexural Strength (MPa)									
	Control mix		SF <sub>5</sub>		SF <sub>10</sub>		SF <sub>15</sub>		SF <sub>20</sub>	
7 Days	2.36	2.38	1.80	1.9	2.10	2.12	2.30	2.27	2.10	2.32
	2.30		1.90		2.00		2.20		2.20	
	2.48		1.90		2.20		2.40		2.60	
	2.40		2.00		2.20		2.20		2.40	
28 Days	2.76	2.74	2.40	2.65	3.00	2.82	2.90	2.93	2.90	2.97
	2.68		2.60		2.60		2.70		2.80	
	2.86		2.70		2.90		3.10		3.20	
	2.40		2.90		2.80		3.02		3.00	
%, increase			-2.50		3.67		7.72		9.19	

\*Percentage increase w.r.t control specimens. Negative sign shows decrease in strength.



**Fig. 4.8.** Flexural strength of blocks with different proportion of silica fumes

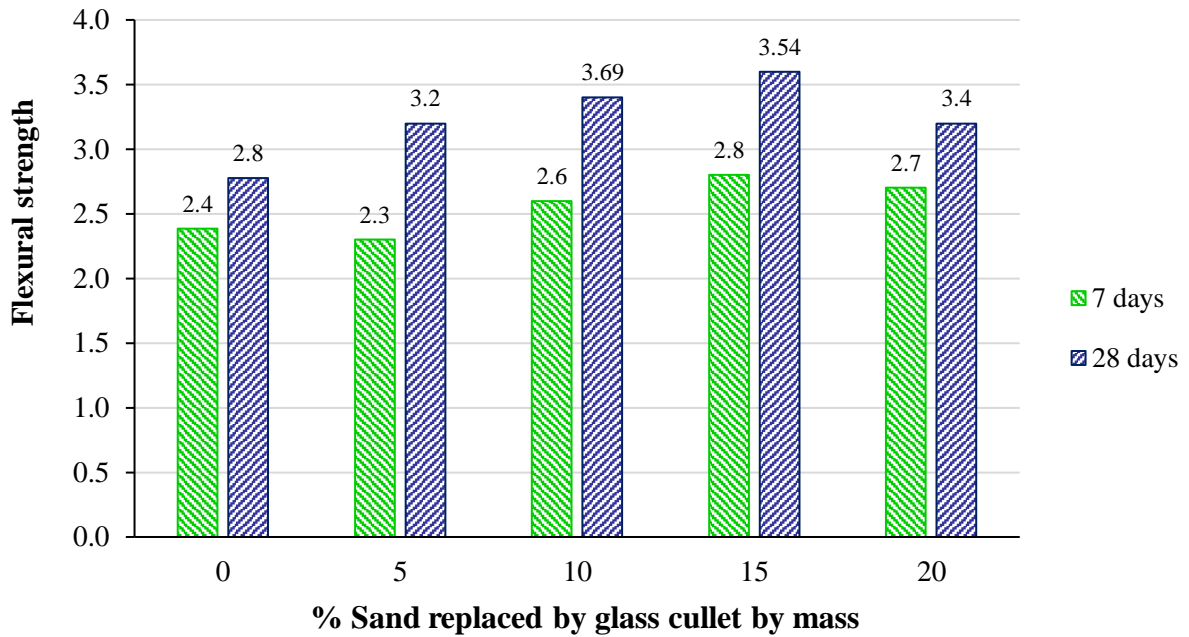
#### 4.4.4 Flexural strength of block specimen when glass is used in the mix.

The flexural strength of block specimen is tested at the end of curing period of 7 days and 28 days is given in Table 4.12. It is observed that the strength of paver block specimen increases as compared to controlled specimen. All the Glass specimens at 5% in the mix shows high flexural strength of paver blocks then the control specimen. Glass replaced at 10% gives the highest value for flexural strength i.e. 3.69 than any other specimen. The increase in flexural strength is 18.30% when 5% glass is added in the mix as cementitious material. For 10%, 15% and 20% increase in strength is 35.60, 30.10 and 26.83 respectively. Outcomes for flexural strength of paver blocks G<sub>0</sub>, G<sub>5</sub>, G<sub>10</sub>, G<sub>15</sub> and G<sub>20</sub> at 7 days and 28 days are shown in the Fig. 4.8.

**Table 4.12.** Effect of replacement of sand with glass cullet on flexural strength (MPa).

Age of test	Flexural strength (MPa)									
	G <sub>0</sub>		G <sub>5</sub>		G <sub>10</sub>		G <sub>15</sub>		G <sub>20</sub>	
7 Days	2.36	2.38	2.36	2.39	2.65	2.64	2.65	2.80	3.45	3.2
	2.30		2.34		2.59		2.94		3.35	
	2.48		2.45		2.74		2.76		3.10	
	2.40		2.41		2.62		2.85		2.9	
28 Days	2.76	2.72	3.25	3.22	3.57	3.69	3.65	3.54	3.55	3.45
	2.68		3.45		3.72		3.45		3.56	
	2.86		3.15		3.69		3.55		3.30	
	2.40		3.03		3.78		3.51		3.39	
%, increase			18.30		35.60		30.10		26.83	

\*Percentage increase w.r.t control specimens.



**Fig. 4.9.** Flexural strength of paver blocks when glass is used in blocks.

#### 4.5 Effect of partial replacement of sand and cement

From the above test result of the block specimen, glass cullet replacement with sand gives the best results for compressive strength and its 28 flexural strength gives more values when it is compared with controlled specimen. Water absorption of 10% glass specimens also passes the IS 15658:2006 specification. So, glass at 10% in the mix gives optimum results. Similarly, cement when replaced alternatively one by one with metakaolin, silica fumes and fly ash, then all the replaced materials give optimum results when mixed in concrete at 15% by weight, when compared with controlled specimen. So, the new mix design was done after the testing of individual material used in the mix. In this design optimum percentage at which specimen gives best result for different material is used in the mix. In this design both sand and cement both are partially replaced with glass and fly ash or silica fume or metakaolin in the paver block. Specimen Id and their corresponding mix are given in the Table 4.13 below.

**Table 4.13.** Specimen Id for different mix proportions of concrete.

Specimen Id	Fly ash (FA) %	Metakaolin (MK) %	Silica Fumes (SF) %	Glass (G) %
FA <sub>15</sub> G <sub>10</sub>	15	0	0	10
MK <sub>15</sub> G <sub>10</sub>	0	15	0	10

SF <sub>15</sub> G <sub>10</sub>	0	0	15	10
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Table 4.14 shows the result for compression test. Specimen Id FA<sub>15</sub>G<sub>10</sub> gives the best result for compressive strength as compared to the controlled specimen. There is an increase in the strength of 23% as compared to the controlled specimen blocks. Specimen SF<sub>15</sub>G<sub>10</sub> gives relatively low strength as compared to SF<sub>15</sub> specimen, but it is higher than that of the controlled specimen. Specimen MK<sub>15</sub>G<sub>10</sub> also gives low strength as compared to MK<sub>15</sub> specimen but higher than that of controlled specimen.

**Table 4.14.** Compressive strength

Age of test	Compressive strength (MPa)							
	Control mix		MK <sub>15</sub> G <sub>10</sub>		SF <sub>15</sub> G <sub>10</sub>		FA <sub>15</sub> G <sub>10</sub>	
7 Days	44.2	44.3	45.9	45.9	46.8	47.3	49.4	48.6
	47.6		46.8		45.6		48.6	
	40.6		45.9		48.7		45.9	
	44.8		45.0		48.1		50.5	
28 Days	52.2	53.2	57.9	57.4	61.3	60.2	64.4	65.52
	52.2		58.9		60.2		66.2	
	53.4		56.7		61.4		66.3	
	54.6		56.1		59.9		61.1	
%, increase			5.45*		9.7		23.1	

\*Percentage increase w.r.t control specimens.

Table 4.15 shows the result for flexural test. Specimen Id FA<sub>15</sub>G<sub>10</sub> gives the best result for flexural strength as compared to the controlled specimen. There is an increase in the strength of 69% as compared to the controlled specimen blocks. Specimen SF<sub>15</sub>G<sub>10</sub> gives relatively low strength as compared to SF<sub>15</sub> and other mixes, but it is higher than that of the controlled specimen. Specimen MK<sub>15</sub>G<sub>10</sub> also very low strength as compared to MK<sub>15</sub> specimen but higher than that of controlled specimen.

**Table 4.15.** Flexural strength results.

Age of test	Flexural strength (MPa)							
	Control mix		MK <sub>15</sub> G <sub>10</sub>		SF <sub>15</sub> G <sub>10</sub>		FA <sub>15</sub> G <sub>10</sub>	
7 Days	2.36	2.38	2.70	2.70	1.94	2.01	3.46	3.52
	2.30		2.86		2.00		3.51	
	2.48		2.60		2.01		3.70	
	2.40		2.64		2.09		3.41	
28 Days	2.76	2.72	3.20	3.30	2.70	2.94	4.80	4.60

	2.30		3.60		3.01		4.65	
	2.86		3.10		3.11		4.45	
	2.80		3.30		2.94		4.51	
%, increase			21.30		8.08		69.11	

\*Percentage increase w.r.t control specimens.

### 5.1 Summary

In this study, mechanical characteristic of concrete paver blocks is investigated. The inclusion of glass cullet as sand substitute (5%, 10%, 15%, 20%) and fly ash, metakaolin, silica fumes as partial replacement of cement (5%, 10%, 15%, 20%) is considered. With inclusion of waste glass cullet, fly ash, silica fumes and metakaolin in concrete mix, the properties of the concrete are enhanced. Based on the present examination, the following conclusions can be made.

### 5.2 Compressive strength

From the present investigation on the compressive characteristics of paver blocks, it is concluded that for a constant water-to-cement ratio, compressive strength increases with the partial replacement of cement with waste supplementary cementitious materials. The highest increase in strength is at the 15% replacement of cement with fly ash, silica fumes and metakaolin. On the other hand, in case of replacement of natural sand with glass cullet, highest increase in the strength is obtained at the replacement level of 10%.

### 5.3 Flexural strength

The flexural strength of the paver blocks increases with addition of glass cullet, fly ash, metakaolin, silica fumes is added in the mix. The maximum increase in the flexural strength is observed in the specimens in which 15% cement is replaced with supplementary cementitious material. On the other hand, 10% replacement of sand with glass cullet the flexural strength obtained is higher than other replacement level. In case of blocks having partial replacement of cement and sand, highest flexural strength is obtained when the replacement level of cement is with 15% fly ash and 10% sand is replaced with glass cullet. The most importantly, enhancement in the strength is double as compared to the controlled specimens.

### 5.4 Water absorption test

The water absorption coefficient obtained for all the mix is well below the limits specified in IS: 15658 (2006). So, all the mixes pass the Indian standards for water absorption test.

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