EFFECT OF PARTIAL SAND REPLACEMENT WITH PVC AND GLASS MIX ON FLEXURAL BEHAVIOR OF CONCRETE

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ABSTRACT

Waste in millions of tons is produced in the world each year and most of it is not recyclable. Furthermore, recycling waste consumes energy and produces pollution. In addition, the accumulation of waste in suburbs and disposal of waste is dangerous for the environment. Using waste material in concrete production is an appropriate method for achieving two goals i.e. eliminating waste and adding positive properties in concrete. Since the green concrete industry is expanding, it is necessary to evaluate concrete that contains waste from all aspects to determine its capability. This research consists of analyzing the use of waste as a partial substitute for sand. Leading waste material that has been used as substitutes is highlighted and the characteristic of the resulting concrete is evaluated in this research. Among other findings, rubber was found to have improved fire resistance and ductility in concrete, and agricultural and Polyethylene terephthalate (PET) wastes were successfully used in non-structural concrete, while glass helped to improve thermal stability. In this research aggregate and sand is replaced by waste materials of Polyvinyl Chloride (PVC) and Glass to check their effect on the mechanical properties. Lab tests were performed to analyze the flexural behavior of concrete samples having waste material. The results show how partial replacement of sand affects the behavior of concrete and based on that specify the conditions where it can be used. The results show that Young's modulus, maximum bending stress, and bending deflection varies with the percentage composition of PVC and glass. Bedding stress and bending deflection decrease with PVC and glass composition up to 35%. Although Young's modulus is fluctuating bending deflection will decrease.

Keywords: waste material, replacement, sand, flexural, partial.

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1. INTRODUCTION

The construction industry employs extensive use of concrete throughout the globe, but it is also the second most often used substance after water. Because of its low cost and wide range of applications, as well as its easy accessibility, it is a popular choice for several different projects throughout the world. People are preferring to live in cities in greater numbers, as the global population grows. The task of supplying enough housing, power, transportation, and other necessities to an ever-increasing metropolitan population is huge especially due to climate change. More than 1.4 billion people are already in danger from natural disasters in almost three out of every five cities with populations above 500,000. Hence, the urgent demand for sustainable concrete, which may be produced by substituting waste materials for cement, sand, or aggregates.

Next to water, concrete is the most widely utilized substance. Cement, aggregate, and water, which are its main components, are abundantly available and inexpensive. Concrete, which is commonly used in the building industry, is made up primarily of these raw elements. Aggregate makes up 65-80 percent of the volume of concrete and has a significant impact on qualities like strength, permeability, volume stability, workability, and durability. To manufacture significant amounts of concrete for worldwide consumption, large quantities of fine and coarse aggregates are necessary. The utilization of waste materials in the preparation of concrete can help to eliminate enormous amounts of waste. This strategy can resolve environmental issues about aggregate mining and waste disposal, as well as problems with aggregate shortages in construction. Alhemshal *et al*. [1].

Resources and waste management have emerged as key concerns for environmental sustainability during the last several years. As the largest consumer of natural resources, construction also creates a significant amount of waste, as do demolition operations that result in large amounts of debris. Using waste in the building material industry is an area of interest for researchers who want to find innovative ways to use resources. The new generation of building materials is also coming up with fresh concepts for environmental sustainability. The main objective of this paper is to analyze the flexural behavior of concrete when partial replacement of fine aggregate is done with locally available wastes of PVC and Glass.

2. EXPERIMENTAL SETUP

Utilization of Wastes is becoming more popular in concrete because they are inexpensive, easy to handle, have high mechanical qualities, are readily available, and are environmentally benign. In this study, PVC and Glass mix is employed as partial replacement to fine aggregates and its effect on the flexural behavior of concrete is studied. Slump cone test, dynamic test, mechanical test, water absorption, linear shrinkage, and mass loss test are all taken into account. The shattered surfaces of broken specimens are likewise subjected to scrutiny. Raw materials and mixing processes are discussed further ahead.

A. Raw Materials

For the production of normal concrete (NC), ordinary Portland cement and crush along with locally available sand are used. The maximum size of the aggregate is 20 mm used for manufacturing both plain concrete and sustainable concrete (SC). Wastes of PVC and Glass are mixed in percentages of 5%, 15%, 25%, and 35% as partial replacement to sand. It may be noted that locally available PVC and Glass particles are being used in this research. No additional treatment is being made on for the waste materials under consideration. The comparison between the flexural properties of NC and SC in shown in Table-2.

B. Mix Design, Casting, and Specimen

For the preparation of NC, a mix design ratio of 1:2:4 (cement: sand: aggregate) is used. Varying proportions of waste materials in incorporated for the testing of specimens. The names of specimens with replacement ratio samples are names are M0, M5, M15, M25 and M35 are marked for ease. The summary for Casting is shown in Table-1.

Table-1. Summary for casting.

Summary for Casting						
Sample Name	Cement : 1 (kg)	Sand : 2 (kg)	PVC in (Kg)	Glass in (Kg)	Aggregates : 4 (kg)	Water : 0.55 (kg)
M0	7.62	15.24	0.00	0.00	30.48	4.19
M5	7.62	14.48	0.38	0.38	30.48	4.19
M15	7.62	12.96	1.14	1.14	30.48	4.19
M25	7.62	11.43	1.91	1.91	30.48	4.19
M35	7.62	9.91	2.67	2.67	30.48	4.19

The total enthalpy of the system can be determined from the following relations:

H= $\int_{Tm}^{Tpcm} \text{Ppcm} * \text{Cpcm} * \text{dTpcm}$ for $T_{PCM}<T_m$ Sensible heat (Solid Phase)

For the flexural testing three beams of each mix (M0, M5, M15, M25, M35) are prepared. The beamlets having dimensions of 18-inch length, 4-inch width and 4-inch height having a volume of 0.167 ft^3 are used for flexural testing. A total of 15 beam samples undergo flexural testing. Shrinkage and Dynamic testing are also performed on the beams before flexural testing. The average of the three specimens is taken as the final value for flexural strength.

C. Flexural Testing

ASTM-C78 is followed. The studied parameters in this test are load-deflection curves, flexural strength (FS), flexural pre-crack energy absorption (FE1), flexural post-crack energy absorption (FE2), flexural total energy absorption (FTE), and flexural toughness indexes (FTI). The three-point loading mechanism is followed. The test setup is shown in Figure-1.

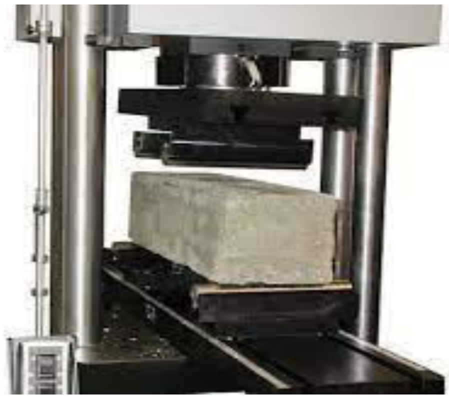

Figure-1. Flexural test setup.

3. RESULTS AND DISCUSSIONS

A. Flexural Behaviour

The relationship between load-deflection curves of NC, M5, M15, M25 and M35 samples under flexural loading is studied by producing load-deflection curves. The maximum resistance was shown by a sample of SC as shown in Figure-2. This means the SC may sustain better than NC after the cracks appear in the concrete.

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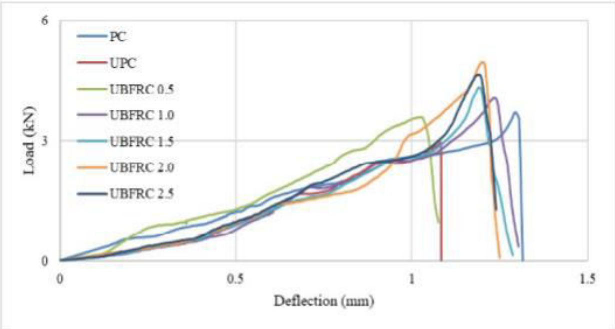

Figure-2. Load deflection curves for NC and SC under flexural loading.

Figure-3 depicts the variation of Young's Modulus with the percentage content of the substitute material (PVC and Glass). The highest Elastic modulus is observed at 5% content of the substitute material with a value of 4.6 MPa and the lowest value of 1.25 MPa at 35% PVC and Glass content. The trend is found is not linear rather it depicts somewhat of a sine wave with a decreasing trend. After 5% of substitute material the Elastic Modulus drops to 1.5 MPa and then rises to have a 4.25 MPa at a PVC and Glass content of 25%. The graph reaches its minimum value of 1.25 MPa at 35% PVC and Glass Content with a decreasing trend between 25% and 35%.

For a better understanding of the variation of Young's Modulus another study with better resolution in the percentage content of substitute material is recommended. A normal concrete already consists of 3 distinct phases (cement paste, aggregate, and the interfacial transition zone). By adding 2 more materials we create a total of 5 phases. As the behavior of the composite depends on all its components, it is very difficult to predict the trend of its material properties. Hence it is better to test a sample of the concrete mix before using it as a substitute for the conventional concrete.

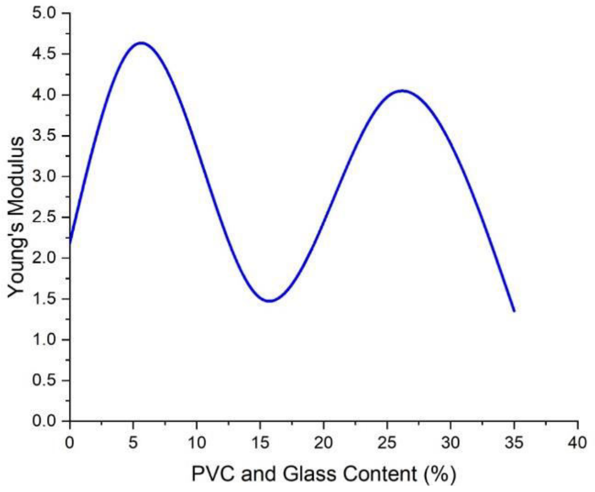

Figure-3. Variation of Young's modulus with percentage variation of PVC and glass content.

Figuue-4 shows the variation of Young's Modulus with the deflection. The current data was calculated by using engineering stress. Normal concrete shows an almost constant Young's Modulus till a deflection of 0.9 mm and after that it drops suddenly and reaches to zero at a deflection of 0.92 mm showing that the material has completely failed. The SC-5 Young's Modulus starts a 4.6 MPa and then shows a down trend till a deflection of 0.2 mm and rises again to have 4.75 at a deflection of 0.5 mm. The Young Modulus then drops sharply to 0 at a deflection of 0.6 mm, where the material fails.SC-15 shows a clear upward trend from 1.5 MPa at no deflection to 1.75 MPa at 0.95 mm after which it drops in a linear fashion to 0 at 1.3 mm (failure point). The third sample (SC-25) shows a deflection of 0.4 mm before having any significant change in its Young's Modulus after which it decreases to 0 at 1 mm. For the last sample SC-35 Young's Modulus remains nearly constant till a deflection of 1.1 mm after which it decreases with a steep slope to 0 at a deflection of 1.3 mm.

Strain hardening is observed in all samples except SC-25 with it being the most prominent in the SC-35 sample primarily due to the crystallization of PVC as it is observed clearly in its stress-strain curve.

The longest plastic region is observed SC-15 with SC-35 at the second number. The normal shows almost no plastic region. The graph shows that with the addition of PVC and glass the plastic and strain hardening region increases but not in a linear manner.

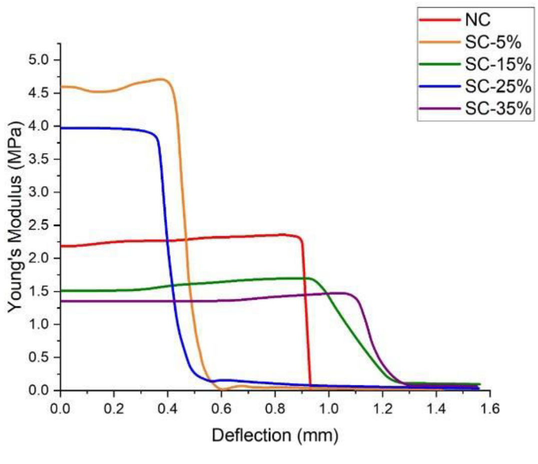

Figure-4. Variation of deflection with changes in Young's modulus.

B. Flexural Properties

It may be observed that maximum flexural strength in the case of M35 as shown in Table-2. The more deflection is experienced in SC than the NC. Under the section of flexural properties, flexural strength (FS), flexural pre-crack absorbed energy (FE1), flexural post crack absorbed energy (FE2), flexural total absorbed energy (FTE) and flexural toughness index (FTI) are shown in Table-2. The FS is increased and has shown maximum value in the case of M35 as compared with the values of other specimens. This increase in FS is caused by the addition of the optimum value of PVC and Glass in concrete. Beyond this, the value of FS is reduced due to the incorporation of the high content of PVC and Glass other than the optimum content. The flexural pre-crack absorbed energy (FE1), flexural post-crack absorbed energy (FE2), flexural total energy absorption (FTE), flexural toughness indexes (FTI) are calculated and shown in Table-2. The flexural pre-crack absorbed energy of M35 is decreased by 15.3%, in comparison with FE1 of PC. There is no flexural post crack absorbed energy in NC samples because NCs' samples are broken into two pieces under peak flexural loading. While all types of SC samples have shown some values of the FE2.

Table-2. Flexural properties.

Concrete Type	FS (MPa)	Δ (mm)	FE1 (Mj/m^3)	FE2 (Mj/m^3)	FTE (Mj/m^3)	FTI (-)
NC	0.91	1.32	2.15	0	2.15	1
M5	0.88	1.025	1.61	0.13	1.74	1.084
M15	0.99	1.234	1.77	16	1.93	1.09
M25	1.06	1.192	1.65	0.2	1.85	1.114
M35	1.21	1.202	1.82	0.12	1.94	1.117

Next to compare the ultimate tensile stress, normal concrete is the best option with a value of 12.3KPa and SC-25 having the lowest UTS among all the samples with a value of 8.3 KPa.SC-5 being the second-best option in this selection criteria with a UTS of 11 KPa while SC-15 and SC-35 being the second-last option with an almost equal value of 9 KPa tensile stress. Similar to the young modulus we fail to see an observable trend in the variation of the max bending stress owing to the presence of 5 phases in the composite which makes the prediction very complex.

For the elastic region the SC-35 specimen shows the maximum elastic deflection (deflection with no permanent change) of 1.1 mm with SC-15 being in second place with a deflection 0.95 mm.SC-25 shows the shortest elastic region with a deflection of only 0.3 mm. SC-5 with a deflection of 0.4 mm has better performance than SC-25 but still falls significantly behind normal concrete sample which has an elastic deflection of 0.92 mm. Similar to the properties we have discussed before elastic deflection fails to show any dominant trend. This trend is shown in Figure-5.

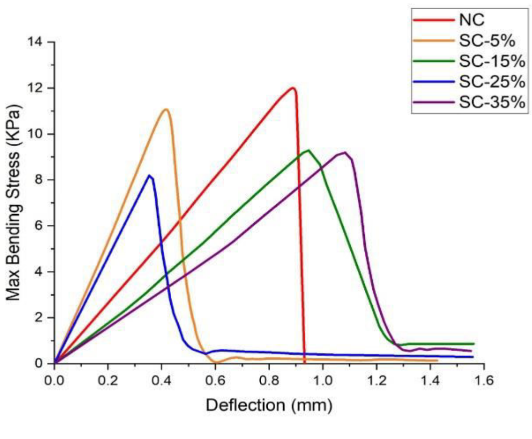

Figure-5. Variation of maximum bending stress with defection.

4. REAL LIFE IMPLEMENTATION

In different civil engineering applications, concrete also goes through several types of loadings together with mechanical loading and dynamic loading. The performance efficiency is affected and controlled by these types of loadings like compressive strength, tensile strength, and flexural strength. The durability of concrete also depends upon these types of loadings. The cracks are produced in concrete due to high water absorption, more linear shrinkage, and less strength of concrete tension (Zia and Ali, 2017).

The phenomenon of differential settlement can also cause cracking in rigid pavements which can be controlled by enhancing the flexural strength property of concrete. One of the issues is the spalling of concrete. The spalling of concrete reduces the durability of concrete and it is caused by different factors such as exposure to high temperatures. Therefore, utilization of waste materials in concrete can help us make the concrete more sustainable and fit for use.

5. CONCLUSIONS

When considering the durability or service life of a material in situ, it must always be considered in light of the unique conditions to which it is subjected. Environmentally friendly additives have recently been investigated for use in eco-cement formulations. An environmentally friendly strategy to utilise disposal resources and reduce pollution is possible with the new generation of building materials that include a variety of wastes. Any kind of concrete may be made by mixing waste elements with experimental research and statistical optimization, allowing for the characterization of novel materials. In the future, further studies will be done to see whether employing acceptable wastes in civil engineering materials has a beneficial or negative impact.

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