EFFECT OF PARTIAL REPLACEMENT OF CEMENT BY MUSSEL SHELL POWDER AND GLASS POWDER ON PROPERTIES OF CONCRETE

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***Abstract*— Considering the recycling approach, a study was conducted to investigate the combined use of mussel shell powder and glass powder as a material for partial replacement of cement. The effect of addition of the glass powder and mussel shell powder on the properties of concrete was studied. Destructive and non-destructive tests were conducted to determine the fresh and hardened properties of concrete. The combined replacement ratio of mussel shell powder and glass powder was 10%, 20%, 30%, 40%. In this study, the concrete specimens prepared with 20% replacement of cement by mussel shell powder and glass powder shows better performance with respect to its mechanical and durability properties.**

Keywords— Glass powder (GP), Mussel shell powder (MSP), Recycling , Waste material

I. INTRODUCTION

Concrete, the most widely used construction material, plays a vital role in global economic growth and infrastructural development. Several investigations have been carried out in the past decades on utilization of waste material for the replacement of cement and aggregate in concrete. Generally, materials with high lime or silica content could be a potential partial substitute to cement. Mussel shell contain nearly 90% of calcium carbonate. Recent investigation has indicated greater scope for their utilization of shell wastes as a construction material [2], [3], [7]. Glass has high silica content, which is the primary requirement for a pozzolanic material. A particle size of 75µm or less is reported to be favourable for pozzolanic activity [5], [8]. The high alkali content of glass is a typical concern for its use in concrete, but studies have shown that finely ground glass does not contribute to alkali-silica reaction [9].

The aim of this work is to study the possible use of mussel shell powder (MSP) and glass powder (GP) in concrete based on the mechanical properties of concrete such as compressive strength, tensile strength, flexural strength, dynamic modulus of elasticity and durability property such as water absorption and sulphate attack.

II. MATERIALS AND METHODS

The OPC 53 grade was used as a main binder. The specific gravity of OPC 53 grade is 3.14. Fine aggregate with specific gravity of 2.60, fineness modulus of 2.85, and water absorption of 1.01% was used. Coarse aggregate with specific gravity of 2.68, and water absorption of 0.61% was incorporated as main component of concrete. Conplast SP430 was used in this study as admixture with a dosage of 0.1% by weight of cement. Water- cement ratio is fixed as 0.5. glass powder and calcined mussel shells were collected from local vendor. The gradation curve of fine aggregate and coarse aggregate are shown in Fig. 1 and Fig. 2 respectively. The chemical composition of cement, mussel shell powder and glass powder are shown in Table I.

The OPC control mix was designated to produce concrete with compressive strength of 30MPa at 28 days. The control mix consisted of cement (383.16 kg), water (191.58 Kg), fine aggregate (678.16 kg), and coarse aggregate (1140.51 kg).Percentage of MSP and GP according to the chemical composition are fixed by using linear programming method. The percentage obtained for MSP and GP are 70% and 30% respectively. In this study cement replacement was done 10%, 20% 30%, 40% with combined mixture of MSP and GP. Nomenclature of mixes is shown in Table II. The mechanical properties were determined by conducting tests for workability, compressive strength, splitting tensile strength, flexural strength and dynamic modulus of elasticity. The durability properties were determined by conducting tests for water absorption and sulphate attack. All test procedures were conducted according to IS specifications. Microstructural examination was also carried out.

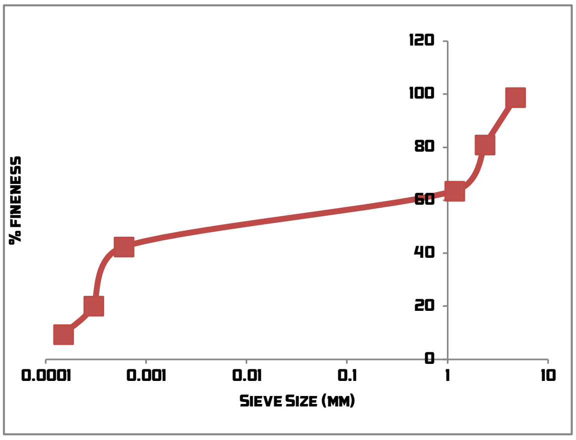


Fig. 1. Gradation curve of fine aggregate

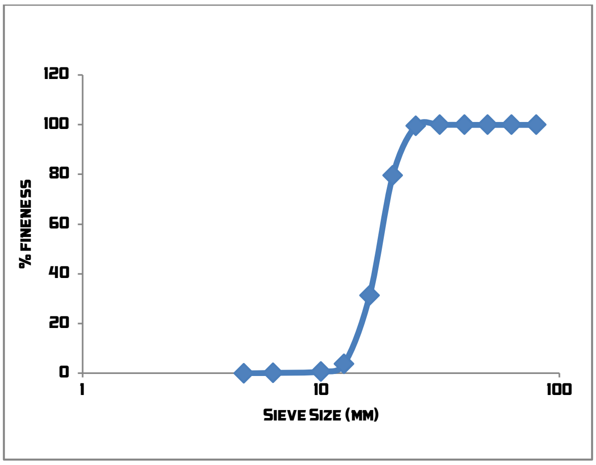


Fig. 2. Gradation curve of coarse aggregate

TABLE I. CHEMICAL COMPOSITION OF CEMENT, MUSSEL SHELL POWDER AND GLASS POWDER

Oxide	**CaO**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**Alkalies (K_2O, Na_2O)**	**SO_3**
Cement	65.15	20.3	5.18	3.21	1.17	0.33	2.82
Mussel shell powder	53.38	0.73	0.13	0.05	0.03	0.46	0.34
Glass powder	10.45	72.08	2.19	0.22	0.72	13.87	-

TABLE II. CHEMICAL COMPOSITION OF CEMENT, MUSSEL SHELL POWDER AND GLASS POWDER

Concrete mix	**Description**
MGC0	Specimen with 0% replacement of cement
MGC10	Specimen with 10% replacement of cement with combined mixture of MSP and GP
MGC20	Specimen with 20% replacement of cement with combined mixture of MSP and GP
MGC30	Specimen with 30% replacement of cement with combined mixture of MSP and GP
MGC40	Specimen with 40% replacement of cement with combined mixture of MSP and GP

III. RESULTS AND DISCUSSION

A. *Properties of concrete*

1) *Workability (Slump Test)*

To determine the effect of addition of MSP and GP on the fresh properties of concrete, slump test was conducted. The slump obtained is shown in Fig. 3. Degree of workability is low when the slump value is within 25-75mm. All the mixes show low workability. As the percentage replacement of cement increased, the workability decreased.

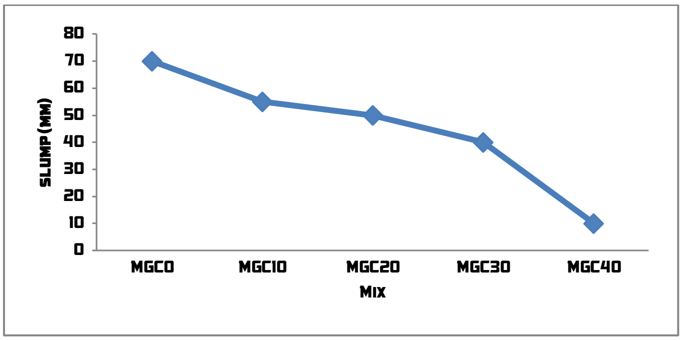


Fig. 3. Slump value of concrete

2) *Activity Index*

Activity index [4] is the ratio between the compressive strength of concrete containing MSP and GP, and the compressive strength of equivalent control concrete at the same age.

Compressive strength of concrete at 7, 14, 28 days is shown in Fig. 4. Compressive strength of control mix at 7, 14, 28 days are 20, 27, 30 MPa respectively. As the percentage replacement increases compressive strength decreased. Cement is much finer than GP and MSP. The fineness of glass powder plays a significant role in its pozzolanic reactivity behavior [5], [8]. It was found that as the dosage of the glass powder increased, the compressive strength of the mortar cubes decreased. The reduction in the strength of glass powder blended mortars is higher at early ages (i.e. 7-day strength) compared to later ages [1]. At 20% replacement level, concrete attained 26.67% higher strength with respect to the characteristic compressive strength of M30 concrete. Compressive strength of concrete decreased beyond 20% replacement.

Activity index at 7, 14, 28 days are shown in Fig. 5. Activity index is decreased at 40% replacement as the age of concrete increases. At 20% replacement level, 80% of target strength was obtained at 28day. Percentage of strength obtained was decreased beyond 20% replacement level.

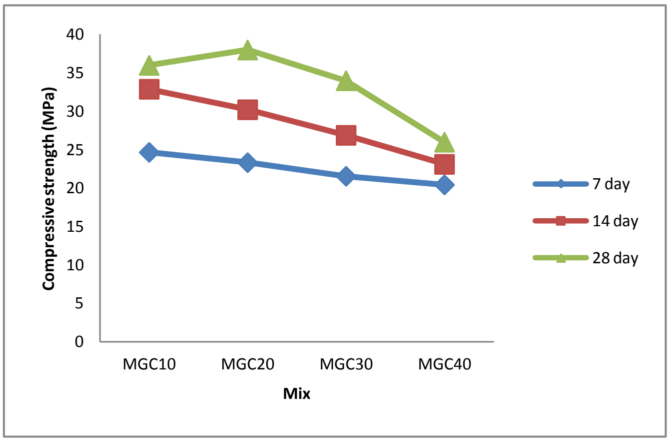


Fig. 4. Compressive strength of concrete

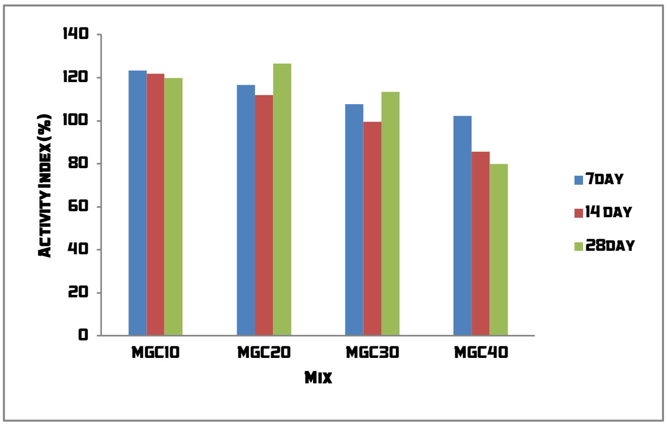


Fig. 5. Activity Index

3) Splitting Tensile Strength

Splitting tensile strength of MGC10 shows approximately similar result when compared with MGC0. As the percentage increases beyond 10%, reduction in splitting tensile strength can be seen. Even if incorporation of mussel shell powder can improve the tensile strength [6], it may decrease due to the increase in glass powder content. The 28 day splitting tensile strength is shown in Fig. 6.

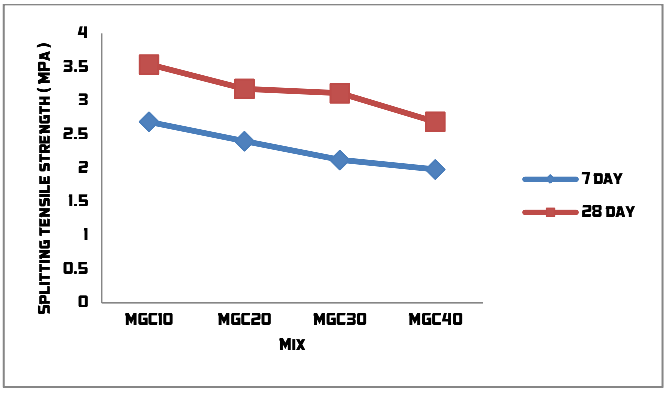


Fig. 6. Splitting tensile strength of concrete

4) Flexural Strength

Flexural strength values obtained for the different mixes is shown in Fig. 7. The flexural strength of concrete for M30 mix is 3.83 MPa. MGC20 and MGC30 showed expected results. The value for flexural strength decreased beyond 20% replacement level. It can be concluded that at 20% replacement have slight increase in flexural strength than other replacement mixes, because the specimen fractured through the aggregate phase which shows ITZ is strong than aggregate phase.

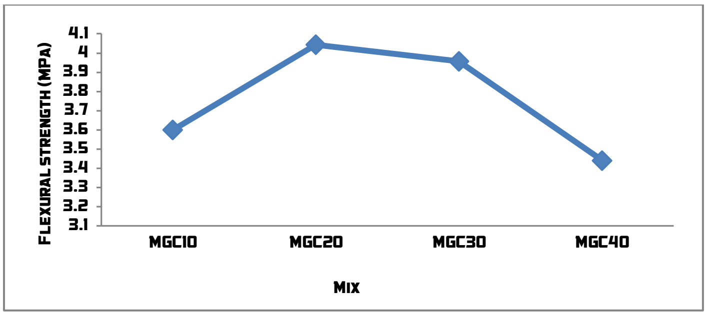


Fig. 7. Flexural strength of concrete

5) Relationship between Compressive Strength, Splitting Tensile Strength and Flexural Strength of Concrete

The applicability of existing relationship between the compressive strength, splitting tensile strength and flexural strength of concrete was investigated. The regression analysis was carried out on the 28day compressive flexural and tensile strength of concrete with substitution of combined mixture of MSP and GP.

The non linear relationship of the compressive strength with splitting tensile strength and flexural strength is shown in Fig. 8 and 9 respectively. The slopes (S) and the intercepts (K) represent the values of the constants in the general equation $f_t = K(f_{ck})^S$.

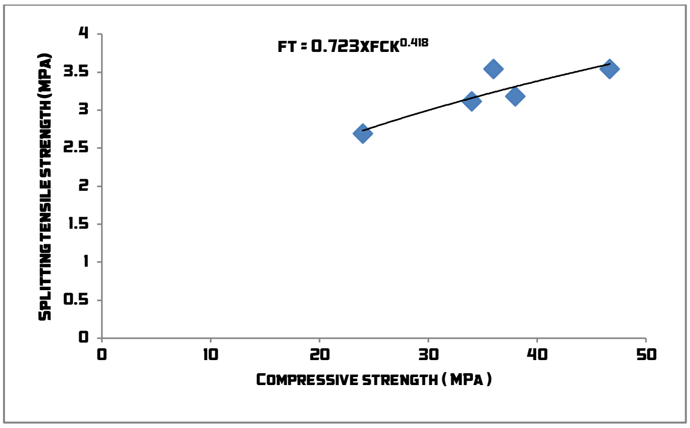


Fig. 8. Relationship between compressive strength and tensile strength of concrete

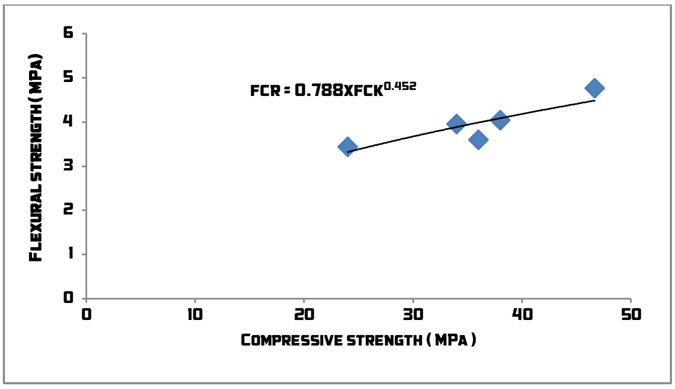


Fig. 9. Relationship between compressive strength and flexural strength of concrete

Based on this experimental investigation, the relationship between the compressive strength and splitting tensile strength of concrete for 28 days found to be $ft = 0.723xfck^{0.418}$. Relationship between the compressive strength and flexural strength of concrete was found to be $fcr = 0.788xfck^{0.452}$.

6) Dynamic Modulus of Elasticity

The variation in dynamic modulus of cylinders for the various mixes is graphically presented in Fig. 10. As the percentage replacement of cement increases dynamic modulus of elasticity decreased. The modulus of elasticity mostly relies in the ITZ between the aggregate and cement paste [6]. ITZ becomes weaker as the percentage replacement increases. During testing MGC40 collapsed through ITZ which shows ITZ is weaker than aggregate phase.

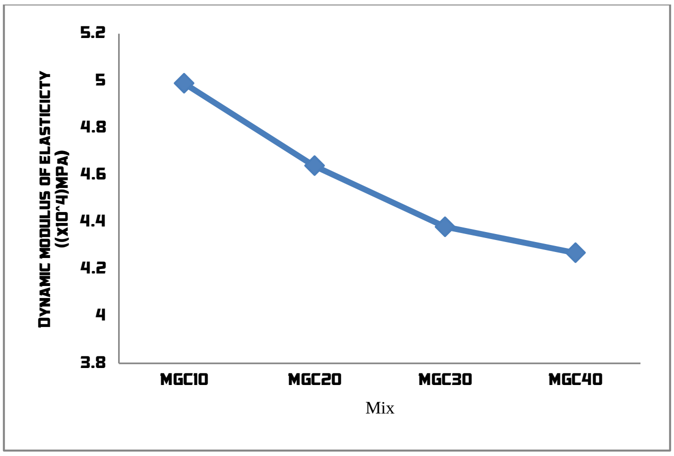


Fig. 10. Dynamic modulus of elasticity of concrete

7) Water Absorption

Water absorption value for different mix is shown in Table III. For all mixes, water absorption is less than 5%.

TABLE III. WATER ABSORPTION TEST OF CONCRETE

Mix	W_1 (kg)	W_2(kg)	Water absorption (%)
MGC0	8.302	8.475	2.084
MGC10	7.998	8.18	2.28
MGC20	7.992	8.266	3.43
MGC30	8.044	8.224	2.24
MGC40	8.062	8.18	1.46

W_1 – Oven dried weight of specimen

W_2 – Weight of specimen after immersing in water for 24hrs.

8) Sulphate Attack

Percentage loss of strength due to sulphate attack is shown in Table IV. As the percentage of replacement of cement increases, there is a higher reduction in the loss of strength. It might be due to the presence of glass powder because GP can greatly improved sulphate resistance without compromising strength [4].

TABLE IV. PERCENTAGE LOSS OF STRENGTH DUE TO SULPHATE ATTACK

Mix	Percentage loss of strength
MGC0	19.05
MGC10	5.56
MGC20	3.51
MGC30	3.27
MGC40	3.20

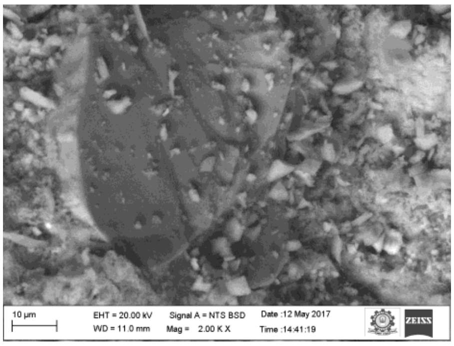
9) Scanning Electron Microscopy (SEM)

Microstructural examination was done on sections from mortar cubes containing 0-40% replacement of cement with MSP and GP. The samples are at an age of 28 day. The microstructural details of the specimens are investigated by using backscatter detector (BSD) imaging.SEM image analysis was done to assess the influence of MSP and GP in concrete.

In Fig. 11, (a), (b), (c), (d), (e) shows the SEM images of the MGM0, MGM10, MGM20, MGM30, MGM40 specimens respectively. Bright white spots indicate the presence of unhydrated clinker grains.

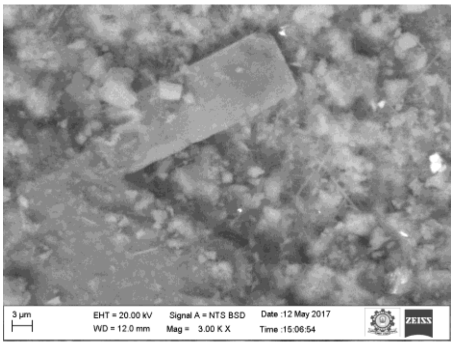
Fig. 11 (a) and (b) shows the SEM images of MGM0 and MGM10 in which formation of CH and C-S-H gel and unhydrated clinker grains can be seen. Fig. 11 (c) shows the SEM image of MGM20 in which needle-shaped crystals (ettringite) is visible. Fig. 11 (c) shows a plate like structure which indicates the presence of CH formation. Fig. 11 (d) shows the SEM image of MGM30 in which a separation can be seen which indicate the weak bonding. The lack of adequate bond between the paste and the aggregate is reflected in the results of mechanical properties of concrete. Fig. 11 (e) shows the CH formation is more than C-S-H gel and unhydrated clinker grains can also be seen. More CH formation may be due to reaction of calcium carbonate present in calcined MSP used in this experimental work.

At 30% and 40% replacement, the C-S-H gel formation is lower compared to the other mixes and CH formation is more compared with C-S-H gel (Fig. 11 (d), (e)). The strength contributing potential of CH is limited because of its lower surface area. That may be the reason for the strength reduction after 20% replacement level. These results are in agreement with the 28 day compressive strength which shows lower compressive strength after 20% replacement level. The glass powder has more alkali content than cement, but these alkalies may be used for formation of C-S-H gel during the pozzolanic reaction which occurs earlier than ASR, therefore not leaving enough alkalies to induce ASR [4].



(a)

(b)



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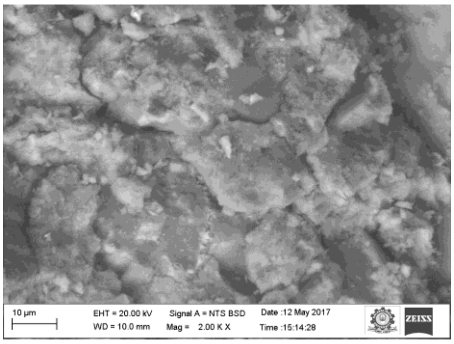
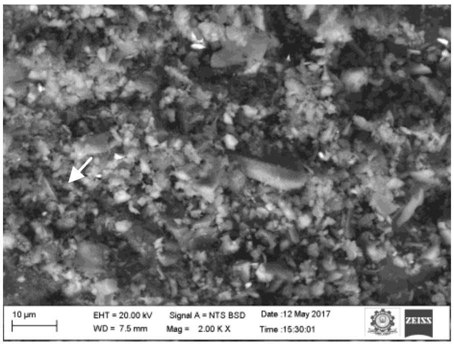


(d)



(e)

Fig. 11. SEM image of (a) MGC0, (b) MGC10, (c) MGC20, (d) MGC30, (e) MGC40

IV. CONCLUSION

In this study the effect of replacing cement by mussel shell powder and glass powder on the mechanical and durability properties of concrete was investigated. The following conclusions can be drawn based on the test results:

- The 3Rs (reduce, reuse and recycle) of integrated waste management are effective in shell wastes and glass waste and applicable to civil construction works.
- Cement can replaced upto 20% with a combined mixture of MSP and GP in which concrete attained 26.67% higher strength with respect to the characteristic compressive strength.
- As the percentage replacement of cement increases beyond 20%, there is a reduction in the compressive strength of concrete. However upto 30% replacement the splitting tensile strength and flexural strength was within the M30 range.
- From SEM images, it can be inferred that beyond 20% replacement the strength reduction is due to the formation of more CH than C-S-H gel. This may be due to the reaction of calcium carbonate in the calcined MSP used for the experimental work.

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