CONCRETE MIX DESIGN USING STEEL SLAG AND GLASS WASTE

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ABSTRACT

The project outlines the study on finding the possibilities of using waste materials in the construction. The materials needed for the research were collected and necessary material test were carried out. Steel slag is used as the partial replacement (10% steel slag and 90% natural aggregate) of coarse aggregate in one mix and glass waste is used to substitute the fine aggregate fully in another mix. Concrete mix design was done manually to obtained mix proportions using two waste materials for M15 and M20. Compressive strength test and split tensile strength test of concrete blocks were conducted and the results obtained were checked for the standard requirements.

Keywords: *Concrete, Steel Slag, Glass Waste, Mix Design, Compressive Strength, Tensile Strength*

1. INTRODUCTION

Concrete mix design is defined as the appropriate selection and proportioning of constituents to produce a concrete of the required properties. In general, concrete mixes are designed in order to achieve a defined workability, strength and durability.

1.1 BACKGROUND

Waste glass is a major component of the solid waste stream in many countries. At present, although a small proportion of the post-consumer glass has been recycled and reused, a significant proportion, which is about 84% of the waste glass generated in UK, is sent to landfill. (Enviros, 2004)

Steel slag is another solid waste that pollutes huge amount of land. It is the major by-product of the steel industry. Druk Iron and Steel in Phuentsholing produces about 9.2 tons of steel slag per day. The steel slag is being recycled during which iron is separated by the magnetic separators to be reused back in the production of steel. The slag which is left behind after iron is being extracted is dumped on an open land. It occupies huge amount of land space and pollutes the nearby environment.

Almost three quarters of the volume of concrete is composed of aggregates. To meet the global the demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete.

Therefore the use of alternative sources, like waste materials, for natural aggregates is becoming increasingly important. In particular the use of steel slag aggregates and glass aggregates in concrete by replacing natural aggregates is a most promising concept and has great potential for future high quality concrete development.

1.2 OBJECTIVES OF THE PROJECT

The main aim of this project is to explore the possibility of utilizing the locally available waste materials (steel slag and waste glass) in the concrete construction.

Another objective is to carry out the concrete mix design using waste materials.

- Glass powder replacing the fine aggregate
- Steel slag replacing the coarse aggregates partially.

1.3 SCOPE OF THE PROJECT

The project carried out determines only the tensile and compressive strength of concrete blocks constructed out of locally available waste materials. The data collected and interpretations are completely based on laboratory testing and findings.

The glasses used are of different types ranging from the bottles used to pack the liquor to the glasses used as construction material (window glass). The steel slags used are from Druk Iron & Steel in Phuentsholing. Material testing was done based on the apparatus available at the College of Science and Technology.

2. LITERATURE REVIEW

The compressive strength of cubic samples after seven days, was increased from 17 MPa without slag to 27 MPa with 60% slag, i.e. increased by about 59%, and increased from 21 MPa with no slag to 36 MPa with 60% slag i.e increased by 42 % after 28 days. (Mohammed, Abbas, & Abbas, 2009)

The flexural force for cylindrical samples increased from 45 kN with no slag to 75 kN with 50% slag, i.e. by about 66% after 7 days, while it increased from 60 kN with no slag to 100 kN with 50% slag, i.e. by about 66%, in which the flexural force also increased by increasing slag content and soaking time. (Mohammed, Abbas, & Abbas, 2009)

The study concluded that compressive strength of concrete improved by 4 to7 % at all the % replacements of normal crushed coarse aggregate with crystallized slag. In case of replacements of fine aggregate, the strength improvements were notably observed at 30 to 50 % replacement level by 4 to 6%. (Nadeem & Pofale, 2012)

It was observed that the compressive strength increased up to 2% replacement of the fine aggregate with PET bottle fibres and it gradually decreased for 4% and 6% replacements. Hence replacement of fine aggregate with 2% replacement will be reasonable. (Ramadevi & Manju, June 2012)

The paper presents the effective utilization of colored glass aggregates in a range of

architectural concretes and their properties tests. (Liang, Zhu, & Byars, 15 September 2007)

3. METHODOLOGY

3.1 MATERIAL COLLECTION

The materials used in carrying out the projects are cement, steel slag, glass, fine aggregate, coarse aggregates and water.

Ordinary Portland cement of grade 43 was used. The size of coarse aggregate used is 20 mm and downgrade. The sand used is of zone II as per IS 383.

3.2 MATERIAL SHREDDING

The bottles were shredded in Los Angeles Abrasion machine to a desired size. These glass were shredded to Zone II as per IS 383 as this grade is the best preferred grade of fine aggregate to be used for construction.

Since the slag is to be used in substitution for the coarse aggregate, the size adopted is 20 mm and downgrade.

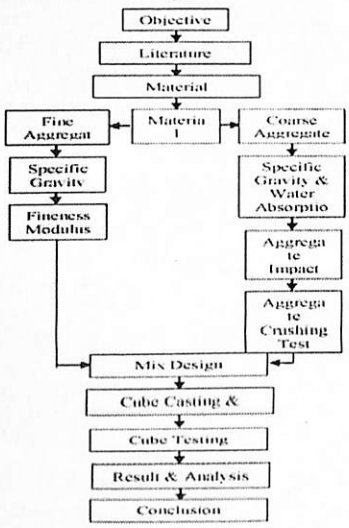

Fig 1. Operational framework

3.3 MATERIAL TESTS

A. DETERMINATION OF FINENESS MODULUS OF FINE AGGREGATES

Fineness Modulus for Sand and Glass which determines the particle size were determined by sieve analysis. Fineness modulus of glass powder and that of fine aggregate was 3.4 and 3.3 respectively.

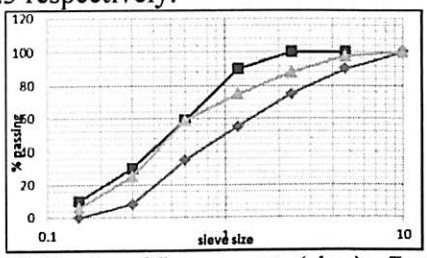

Fig 2. Grading of fine aggregate (glass) – Zone II

The red line in the plot signifies the upper limit of grading while the blue line shows the lower limit. The plot with the green line indicates the actual grading of the glass powder supposed to be used as the replacement of the fine aggregate. The grading plot lying within the upper limit and the lower limit indicates the suitability of the material to be used in concrete mix design.

B. DETERMINATION OF SPECIFIC GRAVITY OF FINE AGGREGATE BY DENSITY BOTTLE

Specific gravity of both fine aggregate and coarse aggregate were determined by density bottle test, the void ratio, its unit weight and the degree of saturation were also computed.

Specific gravity of glass powder obtained was 2.44 and that of sand was 2.54.The result indicates that glass powder has equivalent specific gravity to natural fine aggregates and is acceptable for use in concrete mix design.

C. DETERMINATION OF IMPACT VALUE OF COARSE AGGREGATE

Aggregate Impact value and aggregate crushing value were determined to check the

usability of slag as a coarse aggregate fully or partially in concrete.

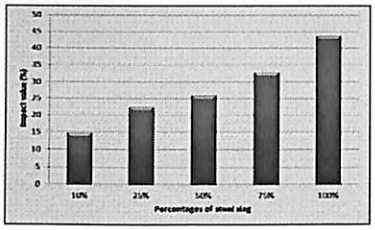

Fig 3. Impact value of aggregate replaced by steel slag in percentage

Low impact value indicates a tough aggregate. The result presented in figure3 shows that with 10% steel slag, an impact value is 14.81%. Since a range of 10 to 20 indicates strong aggregate, 10% steel slag can be used in mix design, replacing the coarse aggregate.

D. DETERMINATION OF COARSE AGGREGATE CRUSHING VALUE

The crushing value for aggregate should not exceed 45% and the crushing value obtained for coarse aggregate (10% steel slag & 90% natural aggregate) was 32.48%.

E. DETERMINATION OF WATER ABSORPTION AND SPECIFIC GRAVITY OF COARSE AGGREGATE

Water absorption and specific gravity for 90% Natural aggregate + 10% steel slag was 0.829% and 2.646 respectively. Specific gravity of the coarse aggregate to be used in concrete mix should be within 2.4 to 2.9.

3.4 CONCRETE MIX DESIGN

Concrete mix design as per Indian Standard recommended method (IS 10262-1982) was followed to determine the mix proportion for M15 and M20 concrete.

Mix proportions obtained from the design are:

1. Cement: Sand: (10% Steel Slag + 90% Natural Aggregate)
   - M15 = 1: 1.957: 3.797
   - M20 = 1: 1.653: 3.203
2. Cement: Glass powder: Natural aggregate
   - M15 = 1: 1.88: 4.063
   - M20 = 1: 1.59: 3.433

3.5 CUBE SAMPLES

Cubes of 15 cm X 15 cm X 15 cm were casted for compressive strength test and cylinder of 10 cm diameter and 15 cm height were casted for split tensile strength.

3.6 CUBE TEST

Compressive strength test and split tensile strength for the cubes cured for 7 days and 28 days were conducted using Universal Testing Machine (UTM).

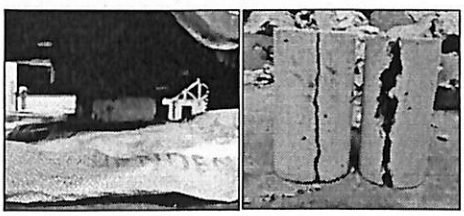

Fig 4. Compressive strength test samples

4. RESULT AND DATA ANALYSIS

Only compression test of concrete cubes are highlighted in this section. Pre material test are all reflected in section 3.3 of this paper.

The compressive strength and split tensile strength obtained at 7 days and 28 days were determined through compression test and compared with the standard requirements.

4.1 DETERMINATION OF COMPRESSIVE STRENGTH

Table1. 7 days and 28 days compressive strength of steel slag concrete

Concrete type	Grade of concrete	7 Days comp. strength (N/mm^2)	28 Days comp. strength (N/mm^2)
Steel slag concrete	M15	11.69	16.30
	M20	12.13	14.73

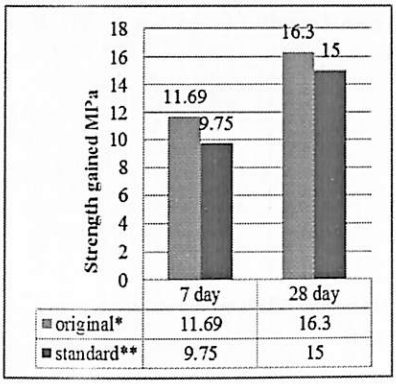

Fig 5. Compressive strength for cubes with steel slag M15

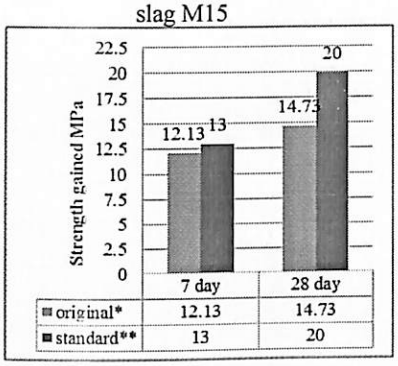

Fig 6. Compressive strength for cubes with steel slag M20

M15 slag concrete shows a good development of strength. This may be due to the proper bond developed between the slag and the cement. However, M20 concrete did not attain the required strength. The concrete failed due to failure of cement paste. The mix proportion reflected in section 3.4 of this paper shows that the ratio of aggregate is lower than that in M15 concrete for same cement content.

Usually, in concretes of higher strengths, the aggregates are strong enough to carry the load imposed on it, but due to the higher content of cement, the concrete fails due to failure in the cement paste. (Alizadeh, Chini, Ghods, Hoseini, Montazer, & Shekarchi, 2003).

Table 2. 7 days and 28 days compressive strength of glass concrete

Concrete type	Grade of concrete	7 Days comp. strength (N/mm^2)	28 Days comp. strength (N/mm^2)
Glass concrete	M15	11.87	15.65
	M20	18.42	26.74

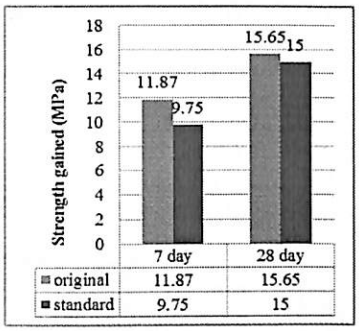

Fig 7. Compressive strength for cubes with glass M15

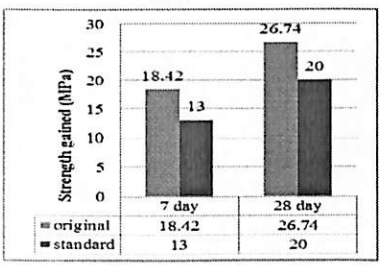

Fig 8. Compressive strength for cubes with glass M20

The test results show a significant development of strength in concrete. The proper grading of glass powder could be one of the reasons for the development in strength.

4.2 DETERMINATION OF TENSILE STRENGTH

The test result indicates the development of tensile strength in concrete casted using the mixture of steel slag and the natural aggregate in comparison to the concrete casted using only the natural aggregate.

Table 3 7 days and 28 days tensile strength of steel slag concrete

Concrete type	Grade of concrete	7 Days tensile strength (N/mm^2)	28 Days tensile strength (N/mm^2)
Steel slag concrete	M15	1.91	2.89
	M20	1.88	2.87
Glass concrete	M15	2.56	3.51
	M20	2.6	3.6

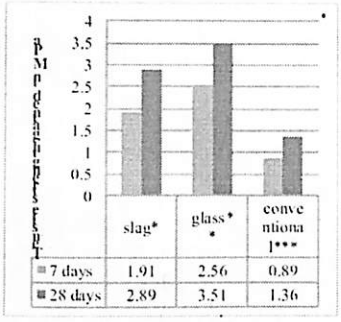

Fig 9. Tensile strength for M15 concrete cubes

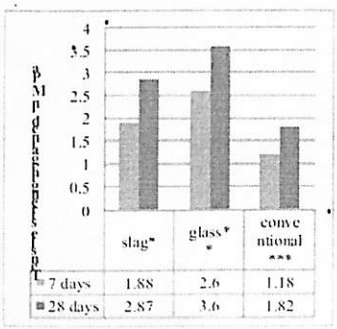

Fig 10. Tensile strength for M20 concrete cubes

The reason for the development of the tensile strength in this case may be due to the usage of steel slag. Steel is supposed to be a very good material to resist tension so the use of steel slag could have resulted in the improvement of tension. This indicates that the new material can be preferred than the natural aggregate alone.

The use of glass powder in place of sand results in a higher tensile value of the concrete. This can be due to the chemical properties of the glass.

Proper grading of glass powder could be another reason. The proportionate mixture of various sizes of grains corresponding to the zone II grading of the Indian Standard could have resulted in a proper bonding of the binding materials.

5. CONCLUSION

Steel slag can be used to replace natural aggregate by 10%. Impact test and crushing test for the mix proportion (10% steel slag and 90% natural aggregate) determines its suitability to substitute natural aggregate. The impact value and crushing value obtained are 14.81% and 32.48% respectively. Also specific gravity and water absorption values were determined to be 2.646 and 0.829% according to the lab results. This result satisfies the aggregate requirement for concrete mix design.

With reference to (IS: 383-1970 cl. 3.4), aggregate impact value shall not exceed 20% by weight for aggregates used for concrete other than for wearing surface and as per (IS: 383-1970 cl. 3.3). The aggregate crushing value shall not exceed 45% for aggregate used for concrete other than for wearing surface. Hence, the aggregate with a mix of 10% steel slag and 90 % natural aggregate can be used as a coarse aggregate in concrete works.

Compression test on M15 concrete cubes showed an increase in the compressive strength for both the concrete mix design. While compression test on M20 concrete cubes showed an increase in strength only for concrete cubes casted using glass powder in place of sand. However, there was a decrease in strength for cubes casted using steel slag. The tensile test for both M15 and M20 concrete cubes casted using the both the concrete mix proportions showed a good development in its strength.

The determination of the compressive and tensile strength for M15 concrete in both the mix design cases concludes that the new material can be applicable in any kind of concrete works pertaining to the strength gained. The concrete with the slag mixture can be used in hydraulic concrete structures as the heat of hydration will be low. Research could be carried out regarding the effect of water on the steel slag and the phenomenon of rusting if any.

It was observed that M20 grade concrete cubes casted using steel slag gave lower compressive strength and is not feasible to be used in construction. For M20 grade concrete cubes casted using glass powder, both compressive and tensile strength increased. Thus, concrete using glass powder replacing the sand can be used in the construction of any kind. Also chemical reaction of the cement with glass power can be explored and studied for better usability.

The concrete casted using the new materials satisfies the strength requirements and thus can be used in concrete constructions.

6.. RECOMMENDATIONS

1. Similar research could be carried with different grading of fine aggregate (Glass powder).
2. Findings can be done using similar type of glass bottles only.
3. Research regarding the effect of water on the steel slag and the phenomenon of rusting if any is possible.
4. Better way of shredding the glass can be implemented and recommended.
5. Studies on concrete of higher strength can be done.
6. Use of different proportions of natural aggregate to slag aggregate can be looked into.
7. Strength study for more than 28 days can be checked.

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