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Experimental Investigation on the mechanical properties of steel slag ceramic concrete

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Abstract: This paper outlines the properties, method of preparation, testing procedure and results of the eco-friendly concrete prepared using steel slag (SS), a waste product from steel industry and ceramic waste (CW). In consuming the waste products in large quantities, always construction industry is in forefront. This paper provides, results on experimental investigations carried out to evaluate the effects of replacing aggregates (fine and coarse with that of steel slag and ceramic waste) in concrete with all other ingredients as constant. An experimental program was designed by analyzing the properties of materials (cement, river sand, crushed granite, steel slag and ceramic waste) used to prepare concrete, designing the mix, casting the specimens, testing the cured specimen and analyzing the mechanical properties of concrete with different proportions of steel slag and ceramic waste. The optimum percentage of replacement for fine aggregate (FA)by steel slag is 40% and for coarse aggregate(CA) by steel slag is 30%, beyond which the compressive strength decreases on further replacement[1].Three mixes were prepared with different replacement levels. Steel slag concrete (SSC) (40% FA replaced by steel slag), steel slag ceramic concrete (SSCC-A) (25% steel slag fine aggregate replaced by ceramic waste) &(SSCC-B) (50% fine aggregate steel slag replaced by ceramic waste) are compared with perfect mix (PM) (with no steel slag and ceramic waste). In all the three mixtures 30% of crushed granite was replaced with coarse steel slag. By adding ceramic waste to SSC, the workability increases. The investigation revealed improvement in the compressive strength, whereas the tensile strength decreases, on the addition of ceramic waste more than 25%. Weight loss in acid immersion, is greatly reduced when ceramic waste is added to SSC. The permeability of concrete with both ceramic waste and steel slag performs better than SSC. Based on the overall observations, it could be recommended that steel slag and ceramic waste could be effectively utilized as coarse and fine aggregates. This Attempt will help to find the viable solution to the declining availability of natural resources and to make eco-balance.
Keywords: Steel Slag; Ceramic Waste; Acid resistance; Compressive strength; Tensile strength.

1. Introduction

Concrete is the largest production of all other materials, in construction Industry. India consumes an estimated 450 million cubic meter of concrete annually, which approximately translates to 1 tonne per Indian. Aggregates are the important constituents in concrete. They give body to the concrete. Due to the rapid growth of industrialization, even some developed countries have encountered some strain in the supply of aggregates in both fine and coarse form. It is of paramount importance, to use more and more environment-friendly materials and industrial wastes in any industry, that too particularly in construction field. Reducing the negative environmental impact caused by the construction industry is a sustainable construction. Enormous studies have been conducted concerning the protection of natural resources, finding solution for the disposal problem, and for reducing the cost of construction by using the waste material.

Presently in India, about 960 million tonnes of solid waste is being generated annually as by-products. An attempt is made to use steel slag, a major byproduct of the steel industry and bulk of ceramic tiles which is not reusable and recyclable, in concrete production. Producing huge quantity of concrete with high quality using these waste materials is an effective measure in maintaining the environment. Thereby, environmental pollution can be reduced to great extent. Using the experimental study, the effective percentage of replacement of aggregate by the waste materials are found, in order to maintain the good quality of concrete with sustainability.

Use of steel slag - a waste industrial byproduct of steel production and ceramic waste provides great opportunity to utilize it, as an alternative to naturally available aggregates (coarse and fine). Steel slag can be effectively used as a replacement material for fine and coarse aggregates [1]. The characterization of steel slag is almost similar to conventional aggregate [2]. But the concrete made from SS and FA in equal proportion proves to be inefficient [3].The SS has very high hardness and strength, so that it can be used as aggregate in concrete [4]. Steel slag can be used in agriculture as it contains the fertilizer components CaO, SiO_2, and MgO [5]. SS concrete has better resistance to deterioration due to its refined pore structure [6]. Due to the size, shape and surface texture of Steel slag aggregates, there develops better adhesion between the particles and cement matrix[7].The addition of nano slag from steel industry in concrete reduces the water absorption up to 15% and thereby, voids are also reduced [8].Effectiveness of slag depends on hydraulic reactivity [9]. Slag based mortar ensures the pozzolanic activity[10]. Slag can be used in high temperature areas [11]. Ground Granulated Blast Furnace Slag (GGBFS) when replaced for cement yields better compressive strength in few hours of thermal curing[12]. In order to allow any feasible breaking up and expansion for long term and short term hydration and to achieve physical and chemical stabilization, steel slag should be aged and stored outdoors in advance or forced spraying for weeks. Only such SS is safe for use in concrete production [13]. Scrap tire particle modified steel slag aggregate concrete decreases the strength of concrete [14]. The decrease in the early compressive strength of ground granulated blast furnace slag is compensated by Metakaolin [15].Using marble sludge dust as a hundred percent replacement material for natural sand reduces the total void content in concrete [16].Here, an attempt is made to introduce ceramic waste in steel slag concrete.

Ceramic waste as coarse aggregate in concrete shows good workability and compressive strength [17, 18]. Ceramic waste also has good tensile and flexural strengths and modulus of elasticity [18]. The Ceramic concrete has low abrasion. Resistance to chloride penetration is more for ceramic concrete when compared to other specimens [17]. Concrete property is greatly influenced by coarse aggregate fraction [19]. The glass ceramics shows maximum bending strength and very nice wear resistance [20].High effectiveness of internal wet curing [21] is seen as the ceramic waste does not interfere in the hydration process [22] even it completely eliminates autogenous shrinkage [21]. The microstructure present in the interfacial transition zone (ITZ) is more compact and stable than that of the natural aggregate–paste [22]. The compressive strength of these concrete improved as the percentage of replacement by ceramic waste increase [21, 22]. As the volume of macro pores decreases, the resistance to aggressive agents increases when ceramic waste is used as aggregate [22]. Glass ceramics can be prepared from nickel slag, blast furnace slag and quartz sand [23]. Ceramics containing 60% weight of steel slag and 40% weight of glass cullet looks suitable for floor tiles [24]. Slag based glass ceramics are cheaper than that of the glass ceramics [25]. Concrete with partial replacement of cement by ceramic waste shows minor strength loss but concrete with ceramic aggregates perform better than conventional concrete [26]. Adding ceramic waste in concrete will provide enough resistance to deterioration and water absorption [27].So, Ceramic wastes are replaced for aggregates and not for binding agent. We need sustainable consumption and strategic waste management to prevent the depletion of global resources.

2. Experimental Detail

2.1 Material

2.1.1 Cement

Ordinary Portland cement of 53grade is used. It is tested as per Indian standard specification (IS 4031 - 1996). Various properties are given in the Table1. Fineness of cement is determined by means of dry sieving. All the properties of cement satisfies the requirements of IS code

Table 1.Properties of cement

Properties	Values
Fineness	5%
Consistency	29%
Initial setting time	45 min
Specific gravity	3.15

2.1.2 Aggregates

River sand is used as a conventional fine aggregate and crushed granite as conventional coarse aggregate. Steel slag, a by-product obtained from the steel manufacturing plant, is crushed into pieces and used as a fine and coarse aggregate along with conventional fine and coarse aggregate. Likewise, ceramic waste is also crushed into fine and coarse form. Various properties of all the aggregates along with the standards, from Indian codal provisions (IS 383 – 1970) are given in Table 2 and Table 3 respectively. The attrition and crushing values of steel slag is higher than the standard values. This has to be taken care when used in runways, roads and pavements, as moving loads place a vital role than the dead load. The water absorption of coarse SS is much higher when compared to that of crushed granite and it also exceeds the standard values prescribed by Indian standard code (IS 2386 - Part III- 1963). SS has to be cured well before using in concrete work. The properties of ceramic wastes are as per requirement. When fully saturated coarse SS is used its water absorbing capacity will be reduced.

Table 2. Properties of various fine aggregates

Properties	River sand	Steel slag	Ceramic waste	Standard values
Voids in sand %	41.17	56	---	---
Specific gravity	2.74	3.0	2.35	2.5 – 2.7
Water absorption %	1.00	1.32	0.71	0.1 – 2.0

Table 3. Properties of various coarse aggregate

Properties	Crushed granite	Steel slag	Ceramic waste	Standard values
Impact test	9.03%	25.26%	17.5%	<45%
Crushing test	36.52%	62.03%	21.8%	<45%
Attrition test	5.40%	4.1%	3.5%	<2%
Specific gravity	2.80	3.84	2.33	2.5 – 2.7
Water absorption	0.5%	5%	2.8	0.1 – 2.0%

2.2 Mix Design

As per the Bureau of Indian standards IS 10262 – 1982, concrete mix design is made for M20 grade concrete with the obtained test results for the good degree of quality control and mild exposure. The mix proportion obtained is1:1.81: 3.85 with the water cement ratio of 0.55.

2.3 Test Details

In order to consider the effect of partial replacement of steel slag and ceramic waste, the proportion of water cement ratio, cement content, method of curing and compaction are kept constant. Cement is not replaced by either steel slag or ceramic waste, because the maximum limit of total addition of performance improver such as fly ash, Granulated slag, Silica fume, Lime stone, rice husk ash, Metakaolin is 5 % during the manufacturing process of ordinary Portland cement as per IS 269- 2013. From the previous results of research, the optimum percentage of replacement for fine aggregate (FA) by steel slag is 40% and for coarse aggregate (CA) by steel slag is 30%, beyond which the compressive strength decreases on further replacement [1]. As a continuation, a part of the steel slag in fine aggregate form is replaced by ceramic waste by 25% and 50%.

The test samples of 1: 1.81: 3.85 concrete mix (Cement: Fine Aggregate: Coarse Aggregate) are produced with crushed granite as coarse aggregate and river sand as fine aggregate. Subsequent test samples are produced with fine and coarse aggregate, progressively replaced by steel slag at 40% and 30% respectively. The another test samples were made ready by replacing 40% steel slag fine aggregate by 25% and 50 % ceramic waste. These four types of samples PM, SSC, SSCC(A), SSCC(B), were then tested to find its basic mechanical characteristics. The various percentages of the materials, for the different types of concrete are shown in Table 4.The water/cement ratio is kept constant at 0.55 throughout the investigation. Nine cubes of 150 x 150 x 150 mm size are cast for each mix and cured in accordance with IS 10086- 1982.The cubes are crushed at 7, 28 and 90 days aging, to determine their compressive strength. The test procedure is carried out to determine the other Mechanical property, tensile strength and for the durability, acid resistance using Hcl and $H_2SO_4$is made for the four types of concrete.

Table 4. Percentage of materials used for different types of concrete

Concrete type	Fine aggregate %			Coarse aggregate %		
	River sand	Steel slag	Ceramic waste	Crushed granite	Steel slag	Ceramic waste
Perfect mix (PM)	100	---	---	100	---	----
Steel slag concrete(SSC)	60	40	---	70	30	----
Steel slag ceramic concrete(SSCC-A)	60	30	10	70	30	---
Steel slag ceramic concrete(SSCC-B)	60	20	20	70	30	---

Before casting the specimens, slump test is carried out as per IS 1199- 1959, to measure the workability. As concrete is primarily meant to withstand compressive stress, compressive strength has received a large amount of attention. The procedure is executed as per the IS 516- 1959, using the universal testing machine. A well known indirect test used for determining the tensile strength of concrete is splitting tests. The test consists of applying compressive line loads along the opposite generators of a concrete cylinder, placed with its axis horizontal between the patterns. Due to the applied line loading a fairly uniform tensile stress is induced over nearly two third of loaded diameter. Due to this tensile stress, the specimen fails finally by splitting along the loaded diameter. Durability tests are performed as per IS code clause 8.2.2.4 of IS 456 – 2000. Acid resistance test is done by weighing the 28 days cured specimen and the same is immersed in sulphuric acid for 90 days. Weight difference is measured after the immersion period. Compressive strength of the specimens are found. The procedure is repeated for hydrochloric acid for different new specimens. The weight loss after 90 days and compressive strength determines its resistance to acid penetration, hence durability of different types of concrete is found. The main objective of this research is to determine the viability of steel slag and ceramic waste in concrete, as fine and coarse aggregate, in a partial optimum percent.

3. Results and Discussion

3.1 Workability

The results of the slump test showed that the workability of all the mixes were low when compared to perfect mix. This is because of the water absorption nature. Steel slag absorbs more water than the ceramic waste and hence the workability of steel slag concrete is very low. When a part of steel slag has been replaced by ceramic waste, the workability increases, as the water absorption property of ceramic waste is low compared to steel slag. Only lesser amount of water is left behind for the hydration of cement in SSC. Some admixtures can be added only when steel slag is used. As the percentage of replacement of steel slag increases the workability decreases and when that steel slag is replaced by ceramic waste the workability increases and almost getting closer to perfect mixas shown in Fig.1. Hence ceramic waste can be added in fine form to increase the workability of SSC.

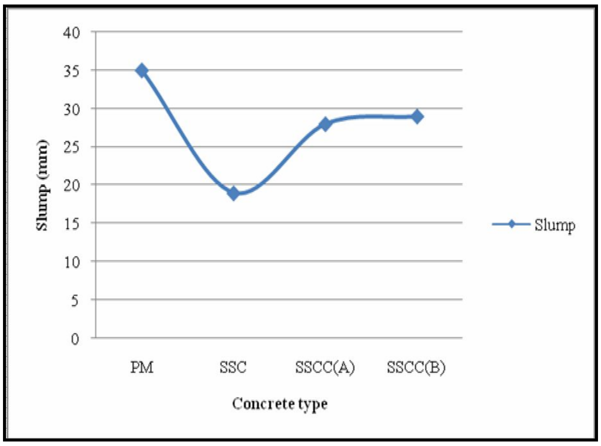

Fig. 1 Workability of different types of concrete

3.2 Compressive strength

In order to find the compressive strength of different types of concrete, three cubes, each at 7, 28 and 90 days is tested in universal testing machine. The individual variation of set of 3 cubes is not more than +/- 15% of the average, as per the acceptance criteria of IS 456- 2000. Their strength comparison is shown in the Fig. 2.

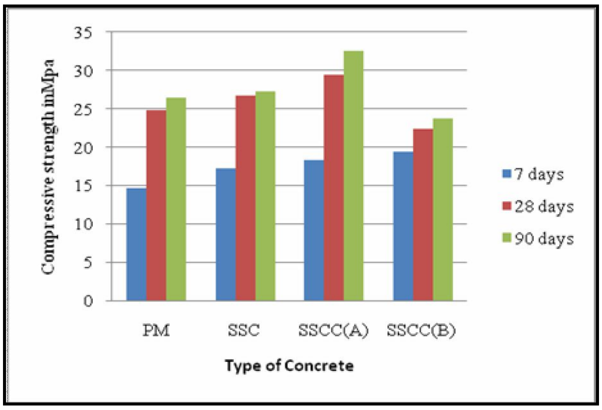

Fig. 2Compressive strength of different types of concrete

From the test results, the early strength of concrete at 7 days increase gradually when aggregates are replaced with steel slag and then by ceramic waste, whereas, at 28 days, increase in fine ceramic waste replacement beyond 25%, reduces the compressive strength by 23.94%. PM and SSC shows almost equal strength at 90 days, as only optimum percentage of replacement has been taken as 40% fine and 30% coarse aggregate by steel slag. When different sets of cubes were tested after 90 days curing, SSCC(A) shows drastic increase in compressive strength by 9.8% when compared to 28 days curing. This is because of the cement surface area and particle size distribution. Since cement is not replaced by any material, the fineness to which the cement is ground will never affect the rate of hydration. It is the fine aggregate which is replaced by steel slag and ceramic waste. Ceramic waste is finer than the steel slag used. Therefore, the strength has increased in the later stage than the initial period when ceramic waste has been introduced due to the better character of fineness. As the age of concrete increases, the formation of secondary calcium silicate hydrated (CSH) gel will initiate, leading to higher strength in later stage.

3.3 Tensile strength

Split tensile test is used to find the tensile strength of concrete in three concrete cylinders, each for 7, 28 and 90 days of curing. As the age of concrete increases from 7 days to 90 days, the flexural strength of concrete also increases for all the four types of concrete. The percentage of increase for the SSC is 10.45% which is more than the SSCC(A & B) is shown in Fig. 3. The flexural tensile strength increases with increase of age and strength of concrete. Concrete is strong in compression but weak in tension. SS, a byproduct of steel, also has the elastic property of steel, to withstand the tensile force, whereas, the ceramic waste is lagging behind in withstanding the tensile force. Therefore SSCC(A & B) shows poor tensile strength than SSC. Even though the tensile strength reduces when ceramic waste is introduced, SSCC(A) shows almost equal strength as SSC. Only when ceramic is introduced on large scale, strength drops below PM. Hence SSCC(A) is better than SSCC(B). By reinforcing the concrete with steel rods, the tensile property can be improved.

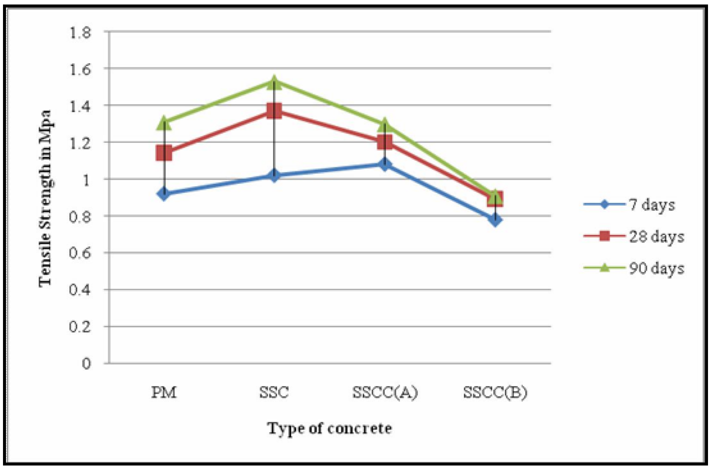

Fig. 3Tensile strength of different types of concrete

3.4 Durability test

The permeability characteristics of different types of concrete can be found by immersing the 28 days cured specimens in acid. Acid used here are sulphuric acid (H_2SO_4) and hydrochloric acid (Hcl). When recycled aggregates are treated in HCl, strength improvements can be achieved [28].The loss in weight of the cube when immersed in H_2SO_4 and HCl for all the types of concrete are shown in Fig. 4 and Fig. 5.When compared with the hydrochloric acid, the weight loss is more when immersed in sulphuric acid, this is because the dehydration rate is high in sulphuric acid than the other. Quantity of CSH gel formed by the hydration process, when immersed in sulphuric acid will be comparatively lower than in Hcl immersion. Corresponding compressive strengths of the specimens are also shown with respect to weight loss. Comparing the four types of specimens, weight loss is more in SSC than the other three. SSCC(A) is almost similar to PM. Hence in the durability point of view SSCC(A) seems good. The outer surface of the cubes immersed in H_2SO_4 has been eroded than the cubes immersed in Hcl are shown in Fig. 6. This is because ceramics generally have good chemical resistance to weak acids and weak bases. However, very strong acids or strong bases tend to produce ion exchange reactions and dissolve the structures. Therefore SSCC(A&B) shows better resistance to acid than SSC.

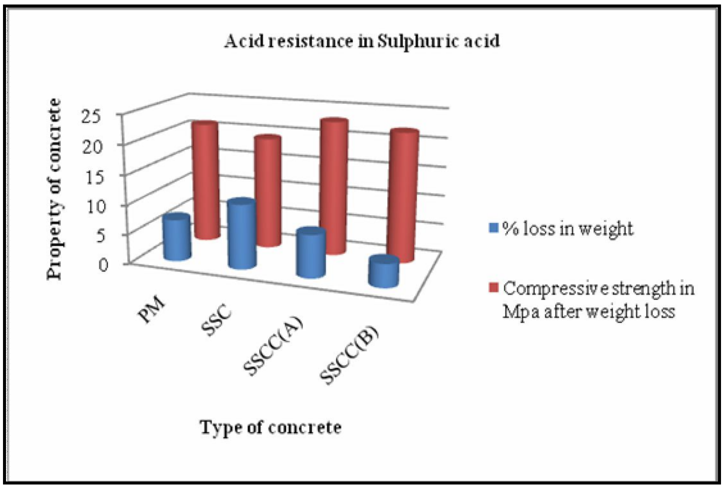

Fig. 4Acid resistance of different types of concrete when immersed in sulphuric acid

When the different types of cubes are immersed in hydrochloric acid, SSC has more weight loss than the other types of specimen. The permeability of steel slag is more, due to it porosity and hence easily attacked by acids. Ceramic material, which is less porous, resists the acid penetration as like crushed granite. With respect to the weight loss, the compressive strength of concrete varies. SSC is poor in durability point of view and thereby introducing ceramic material into it, there is decrease in percentage of weight loss and increase in compressive strength. Therefore SSCC(A) performs well in acid resistance.

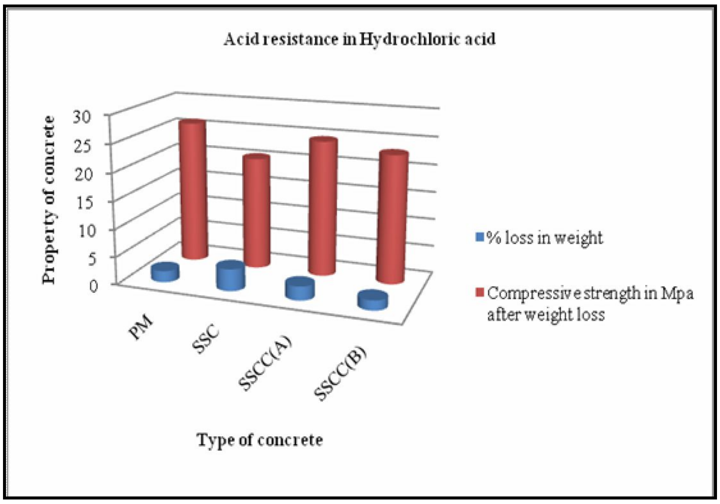

Fig. 5Acid resistance of different types of concrete when immersed in Hydrochloric acid

Fig.6 (a) Cube before immersion in acid, (b) Cube after immersion in H_2SO_4 and (c) Cubes after immersion in HCl.

4. Conclusion

From the experiments conducted the following conclusions were arrived:

1. The workability of steel slag concrete decreases when comparing with perfect mix, due to its high water absorbing nature. When ceramic wastes are added to SSC, its workability increases. Hence SSCC(A& B) is easy to work with, than SSC.
2. SSCC(A) shows very good compressive strength increase by 18% at 90 days curing than the PM at same days of curing. Increase in ceramic waste above 25% reduces the compressive strength of SSC.
3. The tensile strength of the concrete increases with the addition of steel slag to PM. 25% replacement of fine aggregate steel slag by ceramic SSCC(A) shows almost similar tensile strength as perfect mix.
4. Addition of steel slag makes the concrete more susceptible to corrosion whereas, the addition of ceramic waste with steel slag increases its corrosion resistance property. SSCC(A & B) shows better resistance to acid than SSC. The permeability of SSCC(A) is almost similar to PM. Hence SSCC(A) performs well in durability aspect.

Hence ceramic waste can be introduced in SSC in 25% of replacement of fine aggregate steel slag. Further studies can be made by analyzing its micro structure, bond strength, deflection etc., The viability of usage of ceramic waste in steel slag concrete can then be suggested for usage.

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