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Use of furnace slag and welding slag as replacement for sand in concrete

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Abstract

In this project, a study was made to obtain low cost building materials using industrial wastes (welding and furnace slags). The objective of the study is to use these wastes in low-cost construction with adequate compressive strength. Different fine aggregate replacements have been studied by substituting 5%, 10%, and 15% of slag. The waste material was substituted for replacement of fine aggregates and for the preparation of concrete blocks. In this project, we have followed Indian standard methods and arrived at the mix design for M25 grade concrete. Experimental studies were conducted only on plain cement concrete. The preliminary studies were conducted by mixing the slag with the cement concrete cubes of standard sizes. The building material specimens were analyzed for compressive strength as per IS code. For the test and other specifications, it can be concluded that the welding and furnace slags can increase the strength of the concrete. The optimum compressive strength of concretes after 28 days has been found to be 41 N/mm^2 for 5% welding slag and 39.7 N/mm^2 for 10% furnace slag replacements. The results show that 5% of welding and 10% furnace slags replacement with sand is very effective for practical purpose.

Keywords: Slag, Sand replacement, Waste management, Low-cost building materials

Background

Since the large demand has been placed on building material industry especially in the last decade, owing to the increasing population which causes a chronic shortage of building materials, the civil engineers have been challenged to convert the industrial wastes to useful building and construction materials [1]. The challenge for the government is to reduce the waste's harmful impacts to both health and the environment [2]. Concrete industry is particularly important as it is not only responsible for consuming natural resources and energy but also for its capacity of absorbing other industrial wastes and by-products [3]. It is known that about 8 to 10 tons of fresh concrete waste can be produced every day from a concrete-batching plant with a daily output of 1,000 m^3 of concrete [4]. The choice of aggregates is important, and their quality plays a great role; they can not only limit the strength of concrete, but owing to their characteristics, they affect the durability and performance of concrete [5]. The worldwide consumption of sand as fine aggregate (FA) in concrete production is very high, and several developing countries have encountered some strain in the supply of natural sand in order to meet the increasing needs of infrastructural development in recent years [6]. So, there is large demand for alternative materials for fine aggregates in construction industry. To overcome the stress and demand for river sand, researchers have identified some alternatives for sand, namely scale and steel chips [7], waste iron [8], crushed granite fine [6], etc.

Environmental management in developing countries is a complex issue because environmental problems are linked with social and economic aspects, which must be considered in the development of any environmental program or regulation [9]. The problem of waste accumulation exists worldwide, specifically in the densely populated areas [10]. Scale, granulated slag, and steel chips are industrial wastes in the iron and steel industry and cause a nuisance both to the health and environment when not properly disposed [7]. Reuse of industrial solid waste as a partial replacement of aggregate in construction activities not only saves landfill space but also reduces the demand for extraction of natural raw materials [8]. Recent studies showed

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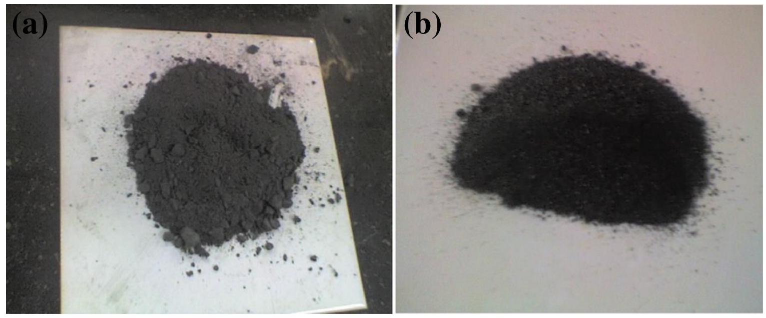

Figure 1 Samples of (a) WS (b) FS.

that slag can also replace with sand in concrete [11-13]. So, the present study focuses to replace sand by welding slag (WS) and furnace slag (FS) in the production of concrete. Properties of aggregates and slag were studied in detail. M25 concrete was designed for various percentages of slag, and compressive strength of concrete was found out.

Methods

Cement

Cement was obtained from single source and single batch from the reputed firm. 43 grade ordinary Portland cement with specific gravity of 3.1 is used in the casting of specimens.

Coarse aggregate (CA)

Crushed granite coarse aggregates of 20-mm maximum size were used.

Water

Potable water available in the NIT Campus conforming to the requirements of water for concreting and curing was used throughout the project.

Fine aggregate

Locally available river sand was used for the present study.

Welding slag and furnace slag

The WS and FS were obtained from local fabrication industries, and they are used to replace fine aggregate partially in the production of concrete. Figure 1 shows the nature and the physical structure of the WS and FS used for the investigation. The physical and chemical characteristics of the welding slag were determined in the laboratory as per standard methods.

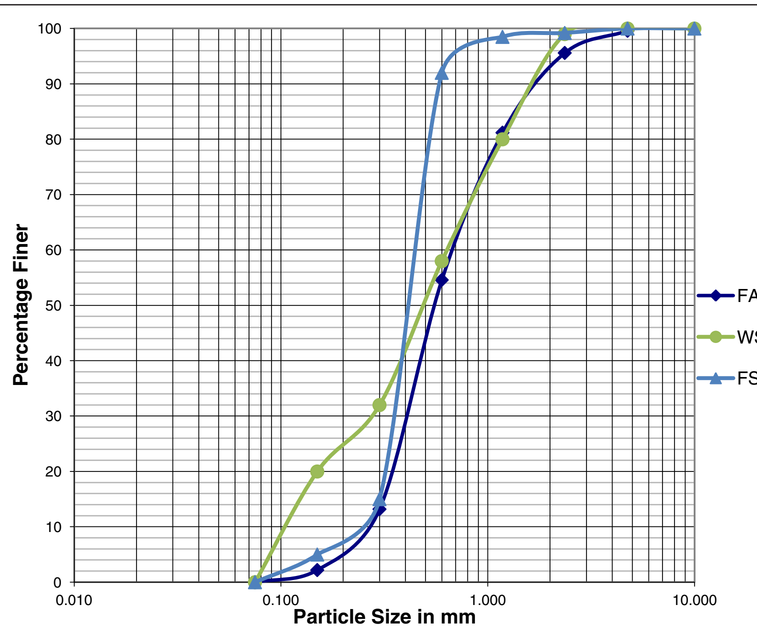

Figure 2 Sieve analysis of ingredients.

Table 1 Physical characteristics of ingredients

Sample number	Properties	FA	CA	WS	FS
1	Specific gravity	2.64	2.72	2.95	1.86
2	Fineness modulus	2.53	7.23	2.12	1.97

FA, fine aggregate; CA, coarse aggregate; WS, welding slag; FS, furnace slag.

Table 2 Chemical characteristics of WS

Metals	Concentration (mg/L)	
	Acid soluble	Water soluble
Fe	26.03	2.11
Mg	6.16	2.03
Zn	0.62	0.05
Al	63.9	5.49
Cu	0.13	0.02
Ca	50.82	22.28
Pb	0.12	0.04
Cr	0.28	0.04
K	2	0.68

Table 3 Chemical characteristics of furnace slag

Metals	Concentration (mg/L)	
	Acid soluble	Water soluble
Fe	4.79	0.04
Mg	3.06	0.54
Zn	0.12	0.01
Al	2.02	0.07
Cu	0.03	0.01
Ca	0.16	0.17
Pb	0.16	0.03
Cr	0.11	0.05
K	0.38	0.56

The X-ray diffraction (XRD) spectra were obtained by using a Rigaku Powder X-ray diffractometer (D-Max/Ultima III, Rigaku Corporation, Tokyo, Japan). XRD and scanning electron microscopic (SEM) analysis were carried out to identify the mineral composition and morphological features of welding slag. The prepared samples were exposed to X-ray with the 2θ angle varying between 10° and 80° with Cu Kα radiation. The applied voltage and current were 40 kV and 30 mA, respectively. SEM investigations of the welding slag samples were conducted in a Hitachi S-3000 H operated at 10 kV (Hitachi, Ltd., Tokyo, Japan). The SEM analysis was done at ×100 magnification to examine the morphological characteristics.

Preparation of test specimen

The experimental investigation has been carried out on the test specimens to study the strength properties as a result of replacing fine aggregate by WS and FS in various percentages namely 5%, 10%, and 15%. The test specimens were cast in steel molds. The inside of the mold was applied with oil to facilitate the easy removal of specimens. The raw materials were weighed accurately. The concrete was mixed thoroughly in dry condition. Initially, 75% of water was added to the dry mix, and they were mixed thoroughly. Then the remaining 25% of water was added to the mix. The mixing was continued until a uniform color was obtained. Fresh concrete was placed in the mold in three layers, and each layer was compacted using tamping rod. Then, the mold were placed in vibrator and compacted. The concrete specimen cast is a 150 × 150 × 150-mm cube. After 24 h from casting, the test specimens were taken out and placed in a curing tank, until the age of the specimens. The prepared specimens were analyzed for workability and compressive strength as per IS standards.

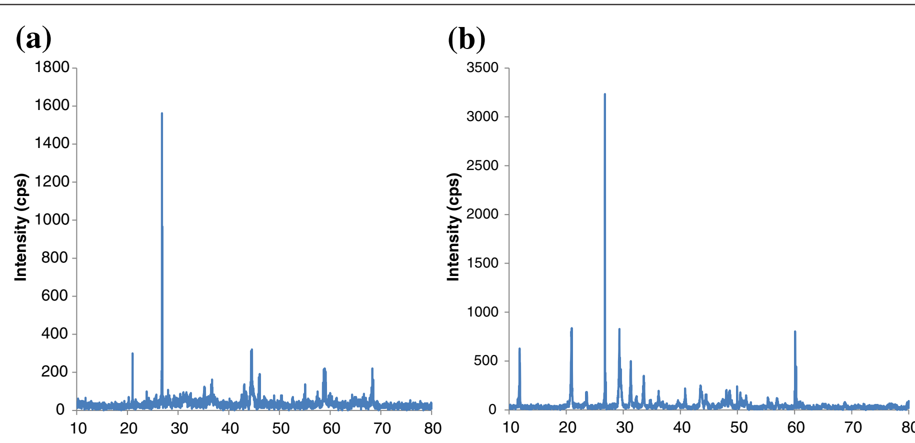

Figure 3 XRD analysis of (a) WS (b) FS.

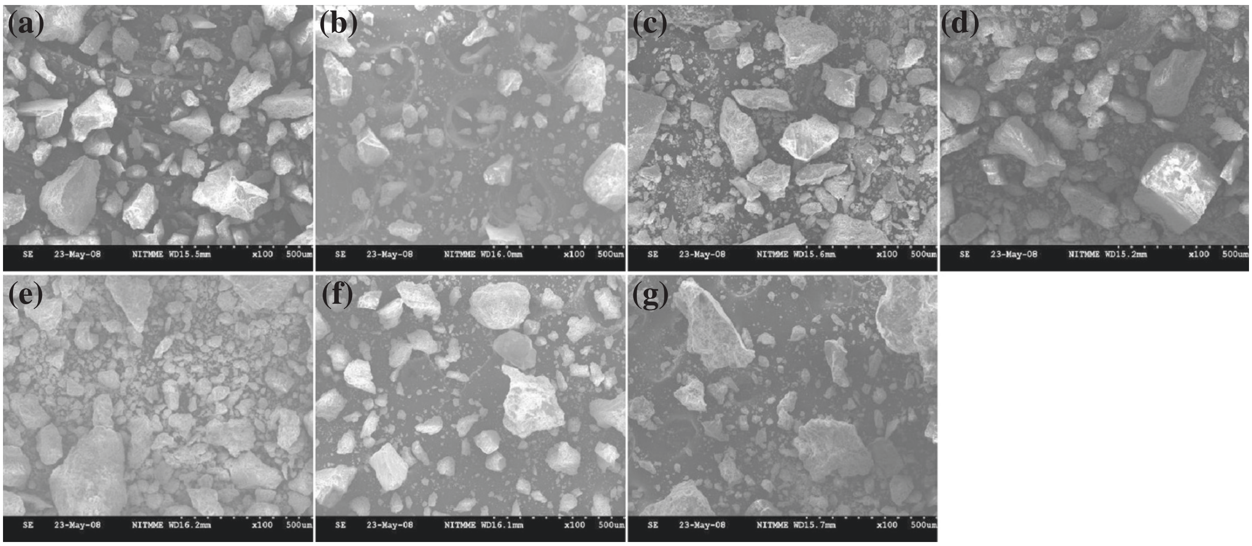

Figure 4 SEM analysis. (**a**) Controlled concrete, (**b**) 5% WS, (**c**) 10% WS, (**d**) 15% WS, (**e**) 5% FS, (**f**) 10% FS, and (**g**) 15% FS.

Results and discussion

Material properties

The size distributions of the materials used in the present study are shown in Figure 2. The size distribution of WS is following the same trend with that of FA. This shows that WS can be used as a replacement for FA in concrete, the FS shows a little bit deviation from sand.

The physical characteristics of ingredients used in the present study are given in Table 1. The specific gravity of WS is greater than that of CA and FA. But the fineness modulus of WS is less compared to CA and FA. The specific gravity and fineness modulus of FS is very less in all the cases. The chemical characteristics of WS and FS are given in Tables 2 and 3, respectively. The WS contains higher amount of Fe, Al, and Ca. These metals are highly soluble in acid than that of water, but the metal contents of FS are very less compared to WS. Since the water solubility of metal in WS and FS, is very less in nature, attack on steel due to this metal is negligible (except Ca and Al in the case of WS). The XRD of WS and FS are shown in Figure 3. The SEM images of controlled concrete and WS and FS added concrete are shown in Figure 4.

The mix was designed for M25 grade of concrete using IS method of mix design. The material properties used in the mix design are given in Table 4, and the mix proportion for making cubes for control concrete and various percentage of replacement of sand with WS and FS are given in Tables 5, 6, 7, and 8.

The variation of compressive strength for various percentage replacement of sand with welding slag for seventh and 28th day is shown in Figure 5. The seventh day compressive strength of concrete increases with the increase in slag concentration up to 10% of sand replacement. Seventh day compressive strength of concrete increases from 17 to 27.8 N/mm^2 for the WS concentration increment of 5% to 10%. Fifteen percent WS concentration also shows the seventh day compressive strength than that of controlled concrete. The seventh day compressive strength

Table 4 Material properties for concrete mix

Properties	Values
Specific gravity of cement	3.1
Specific gravity of water	1
Specific gravity of sand (FA)	2.64
Specific gravity of coarse aggregate (CA)	2.72
Dry rodded bulk density of coarse aggregate (kg/m^3)	1634.8
Fineness modulus of sand (FA)	2.53
Fineness modulus of coarse aggregate (CA)	7.23
W/C ratio for 43 grade cement	0.44
Fineness modulus of welding slag	2.12
Specific gravity of welding slag	2.95
Fineness modulus of furnace slag	1.97
Specific gravity of furnace slag	1.86

Table 5 Mix proportion for controlled concrete

Grade of concrete	Slump (mm)	Quantities per m^3 of concrete (kg)			
		Water (L)	Cement	Sand	Aggregate
M25	0 to 25	188	427.27	700.40	1,057.72
	25 to 50	194	440.91	672.95	1,057.72
	50 to 75	200	454.55	645.50	1,057.72
	75 to 100	206	468.18	618.04	1,057.72

Table 6 Mix proportion for 5% replacement of sand

Grade of concrete	Slump (mm)	Quantities per m^3 of concrete (kg)					
		Water (L)	Cement	FS	WS	Sand	Aggregate
M25	0 to 25	188	427.27	24.67	39.13	665.38	1,057.72
	25 to 50	194	440.91	23.71	37.60	639.30	1,057.72
	50 to 75	200	454.55	22.74	36.06	613.22	1,057.72
	75 to 100	206	468.18	21.77	34.53	587.14	1,057.72

FS, furnace slag; WS, welding slag.

Table 7 Mix proportion for 10% replacement of sand

Grade of concrete	Slump (mm)	Water (L)	Quantities per m^3 of concrete (kg)				
			Cement	FS	WS	Sand	Aggregate
M25	0 to 25	188	427.27	49.35	78.26	630.36	1,057.72
	25 to 50	194	440.91	47.41	75.20	605.65	1,057.72
	50 to 75	200	454.55	45.48	72.13	580.95	1,057.72
	75 to 100	206	468.18	43.54	69.06	556.24	1,057.72

FS, furnace slag; WS, welding slag.

Table 8 Mix proportion for 15% replacement of sand

Grade of concrete	Slump (mm)	Water (L)	Quantities per m^3 of concrete (kg)				
			Cement	FS	WS	Sand	Aggregate
M25	0 to 25	188	427.27	74.02	117.40	595.34	1,057.72
	25 to 50	194	440.91	71.12	112.80	572.01	1,057.72
	50 to 75	200	454.55	68.22	108.19	548.67	1,057.72
	75 to 100	206	468.18	65.32	103.59	525.34	1,057.72

FS, furnace slag; WS, welding slag.

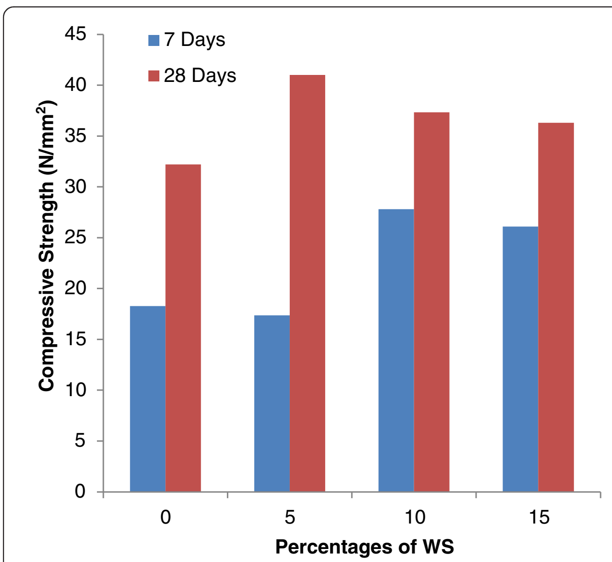

Figure 5 Relationship between WS percentage and compressive strength.

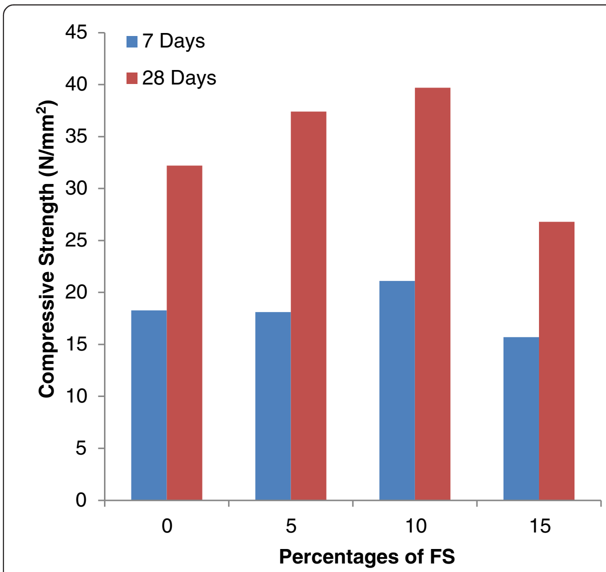

Figure 6 Relationship between FS percentage and compressive strength.

of controlled concrete is found to be 18.27 N/mm^2, but the 28th day compressive strength of concrete shows an optimum value at 5% WS concentration. The 28th day compressive strength of 5% sand replacement concrete has been found to be 41 N/mm^2. Then, the compressive strength of concrete is reduced to 36.3 N/mm^2 as expected earlier, while the 28th day compressive strength of controlled concrete is 32.2 N/mm^2. Also, 10% and 15% sand replacement shows more compressive strength than that of controlled concrete. This indicates that up to 15% sand replacement with WS will increase the compressive strength of concrete, but for practical purpose, 5% of WS is very effective.

Similarly, the variation of compressive strength for various percentages of FS for the seventh day and 28th day is shown in Figure 6. The seventh day compressive strength did not show any difference by the addition of 5% FS. But the compressive strength increases to 21.1 from 18.11 N/mm^2 for 10% FS addition, and after that it reduced to 15.7 N/mm^2 for 15% FS addition. The 28th day compressive strength of concrete increases with FS addition up to 10% and reduces. The 28th day compressive strength of 10% sand replacement concrete has been found to be 39.7 N/mm^2. This optimum value is less than that in the case of WS. Then, the compressive strength of concrete is reduced to 26.8 N/mm^2. Five percent sand replacement shows more compressive strength than that of controlled concrete. This indicates that up to 10% sand replacement with FS will increase the compressive strength of concrete. But for practical purpose, 10% of FS is very effective.

Conclusion

The furnace and welding slags have been utilized in the work by using it in the building materials as addition to concrete. WS and FS concretes showed better performance towards compressive strength. The compressive strength on seventh day of concrete cubes increases from 10% to 15% replacement of sand by WS than the reference materials. Similarly 10% of FS shows an optimum strength of 21.1 N/mm^2. The compressive strength on 28th day of concrete cubes increases from 5% to 15% of replacement of sand by WS than the reference materials. The optimum compressive strength of slag concretes has been found to be 41 N/mm^2 for 5% WS and 39.7 N/mm^2 for 10% FS. The results show that 5% of WS and 10% FS replacement with sand is very effective for practical purpose.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
STR gave guidance to SP, who conducted the experiments on furnace slag as a replacement material for sand. RG gave guidance to SR, who conducted the experiments on welding slag as a replacement material for sand. PVN analyzed the results and compiled them into a journal format. All authors read and approved the final manuscript.

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