Utilization of Induction Furnace Slag in Concrete as Coarse Aggregate

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Abstract

An experimental investigation was carried out to explore the suitability of utilizing induction furnace slag as coarse aggregate in concrete. Cylindrical concrete specimens (100 mm by 200 mm) were made varying the W/C ratio (0.45 and 0.50), cement content (340 kg/m^3), and sand to aggregate volume ratio (0.44 and 0.48). The concrete specimens were tested for compressive strength and splitting tensile strength at the age of 28 days. For comparison, similar investigation was also carried out on burnt clay aggregate commonly used in Bangladesh. Experimental results show that slag aggregates absorb less water compared to the burnt clay aggregates. Compared to burnt clay aggregate, concrete made with induction furnace slag aggregate gives more workability, compressive strength and splitting tensile strength. For obtaining the maximum compressive strength and splitting tensile strength, the optimum amount of replacement of burnt clay aggregate by induction furnace slag aggregate is found at 50%.

Keywords: Aggregate; Concrete; Compressive strength; Induction furnace slag.

1. INTRODUCTION

Utilization of sustainable construction material and technology can be considered as an essential tool to ensure sustainable environment. Due to growing environmental awareness, as well as stricter regulations of managing industrial by-products, the world is greatly concerned finding ways to utilize the by-products as secondary raw materials in other industrial branches. In Bangladesh, most commonly used coarse aggregate is burnt clay aggregate (produced by crushing clay burnt blocks, locally known as brick). Due to rapid urbanization in the country, the demand of aggregate is increasing every year. In 2012, 8.6 billion bricks were produced (to use as coarse aggregate in concrete, to construct walls etc.). It was also estimated that the demand of bricks is increasing every year by 5.3% (Hossain, 2012). But brick industries are associated with a lot of negative environmental impacts. Therefore, it is necessary to find out possible alternative resources that can be used as coarse aggregate in construction works. An extensive study on recycling of demolished brick aggregate concrete as coarse aggregate was carried out for the sustainable use of construction materials in Bangladesh (Mohammed et al, 2015). Also, it is necessary to find further alternative building materials such as steel slag, which is a by-product of steel industry. The utilization of steel slag in concrete as coarse aggregate will help achieve sustainable use of construction materials and will also reduce the emission of greenhouse gases during the production of burnt clay aggregate. Raza et al (2014) conducted a study by replacing natural aggregate with iron slag aggregate at different replacement ratios, such as 0%, 10%, 20%, 30%, 40% and 50%. The results were compared with the results obtained for conventional concrete. It was concluded that utilization of iron slag in concrete will enhance the compressive strength of concrete. Hiraskar and Patil (2013) also investigated the possibility of utilization of blast furnace slag as aggregates in concrete. It was found that similar level of strength of concrete can be obtained by utilizing steel slag as concrete made with natural aggregate. It is clearly understood that utilization of blast furnace slag in concrete as coarse aggregates has no negative effects on the short term properties of hardened concrete. However, it is still necessary to understand the properties of fresh and hardened concrete, if induction furnace slag aggregate is used to replace conventional brick aggregate. With this background, this study has been planned.

2. EXPERIMENTAL METHOD

Slag aggregate sample was collected from a crushing plant of induction furnace slag of a local steel manufacturing company. The slag and brick aggregates were tested for grading, unit weight, abrasion, specific gravity, absorption capacity and abrasion as per ASTM standards. The maximum size of aggregate was 20 mm and the grading of aggregates was controlled as per ASTM C33. Natural river sand was used as fine aggregate. The physical properties of coarse and fine aggregates are summarized in the **Table 1**. The air content in concrete was assumed to be 2% as no air entraining admixture was used. The mixture proportions are summarized in **Table 2**. High-range water reducing admixture (4 ml per kg of cement) was used for W/C = 0.45.

Table 1. Physical properties of coarse and fine aggregates

Type of aggregate	Specific gravity	Absorption capacity (%)	SSD unit weight (kg/m^3)	Abrasion (%)	FM
BC (Brick Chips)	2.14	19	1211	38.8	Controlled as per ASTM- C33
IFS (Induction Furnace Slag)	2.65	2.62	1550	35.2	
Fine Aggregate	2.59	3.30	1520	-	

Table 2. Mixture proportion of concrete

Replacement Ratios (%)		Cement content (kg/ m^3)	s/a	W/C	Case ID	Unit content (kg/m^3)				
						Cement	Fine Aggregate	Coarse Aggregate		Water
BC	IFS							Brick Chips	IF Slag	
0	100	340	0.44	0.45	0%BC+100%IFS-0.45	340	809	0	1053	153
				0.50	0%BC+100%IFS-0.50	340	790	0	1028	170
25	75			0.45	75%BC+25%IFS-0.45	340	809	213	790	153
				0.50	75%BC+25%IFS-0.50	340	790	208	771	170
50	50			0.45	50%BC+50%IFS-0.45	340	809	425	527	153
				0.50	50%BC+50%IFS-0.50	340	790	415	514	170
75	25			0.45	25%BC+75%IFS-0.45	340	809	638	263	153
				0.50	25%BC+75%IFS-0.50	340	790	623	257	170
0	100			0.45	0%BC+100%IFS-0.45	340	809	851	0	153
				0.50	0%BC+100%IFS-0.50	340	790	831	0	170

BC- Brick Chips, IFS – Induction Furnace Slag, W/C = water to cement ratio

Cylindrical concrete specimens (100 mm by 200 mm) were made with different W/C ratios (0.45 and 0.50), sand to aggregate volume ratio = 0.44, and cement content = 340 kg/m^3. Brick aggregates (BC) were replaced with IFS by 0% (i.e., no replacement), 25%, 50%, 75% and 100% (i.e., full replacement). The grading curves of coarse and fine aggregates satisfy the requirement of ASTM C33 as shown in **Figure 1**. CEM Type II/A-M cement (as per BDS EN 197–1:2000) was used. Tap water was used for mixing and curing of concrete. After mixing concrete, slump was measured and then concrete specimens were made as per ASTM C31M–03. The specimens were cured under water till the time of testing. The specimens were tested at 7, 28, 60 and 90 days for compressive strength and tensile strength as per ASTM C39 and C496 respectively.

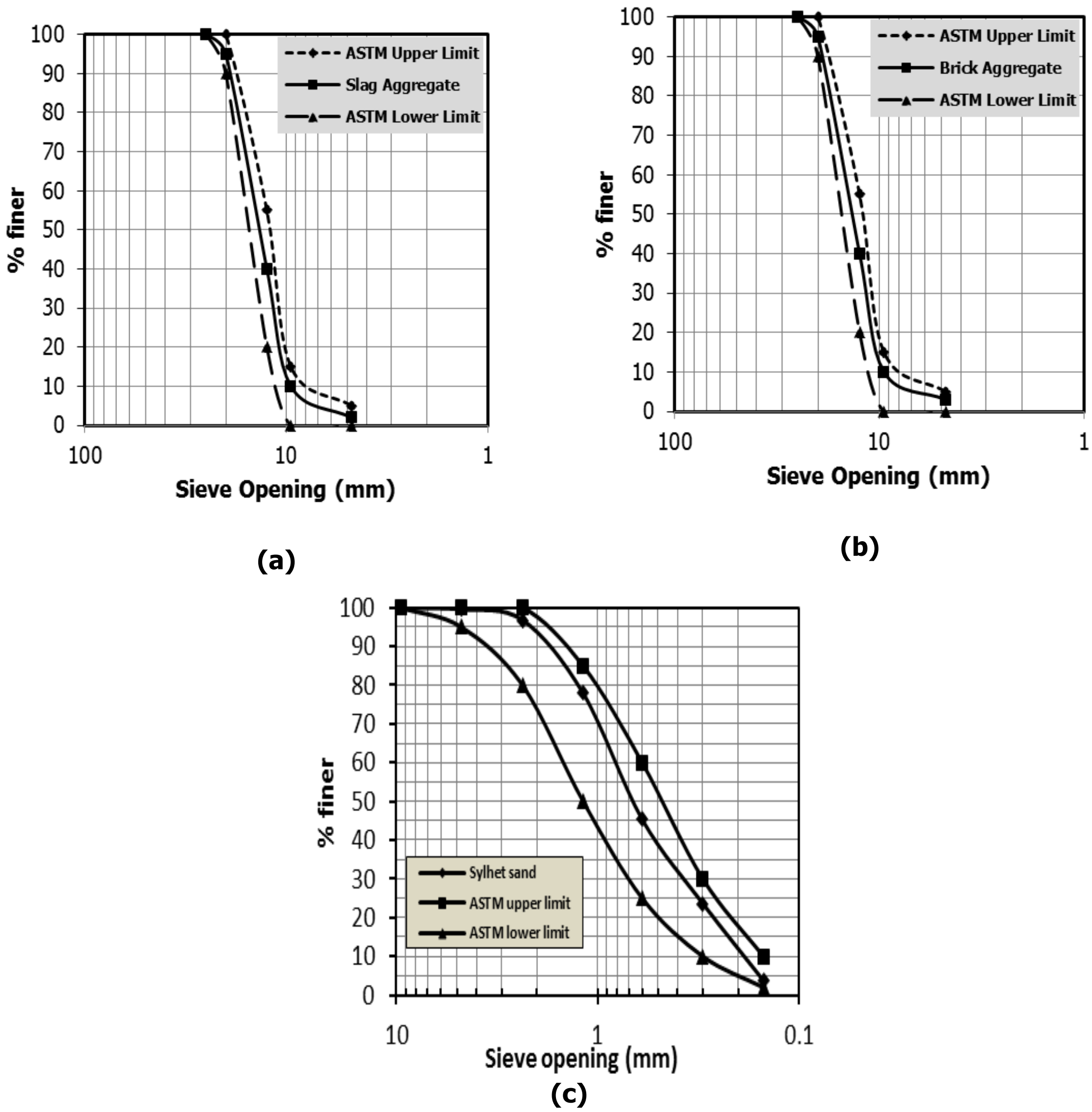

Figure 1. Grading curve of aggregates (a, b – coarse aggregates; c – fine aggregate)

3. RESULTS AND DISCUSSION

3.1 Workability of Concrete

The workability of concrete (measured by slump test) made with different replacement ratios of induction furnace slag is shown in **Figure 2**. It was observed that the workability of concrete increased with the increase of replacement of brick aggregate by induction furnace slag. Similar results were also obtained by Yuksel and Genc (2007). The reason of increase in slump with the increase of replacement ratio of induction furnace slag can be attributed to the lower absorption capacity of IFS aggregate compared to the BC. Another reason may be related to the shape of the IFS aggregate, IFS aggregates have more blunt edges compared to BC. It was also observed that, with the increase of s/a ratio (from 0.44 to 0.48), workability of fresh concrete reduced. It is due to the increase of amount of fine aggregate (sand) in concrete. With the increase of sand content, the total surface area of aggregate would also increase and therefore relatively more lubricating material would be required to increase slump.

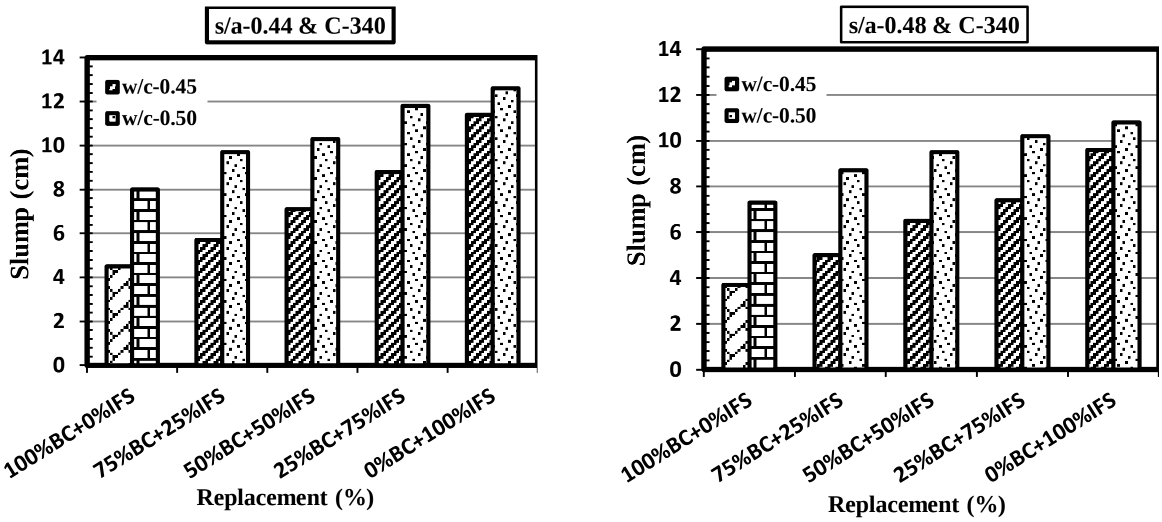

Figure 2. Workability of concrete

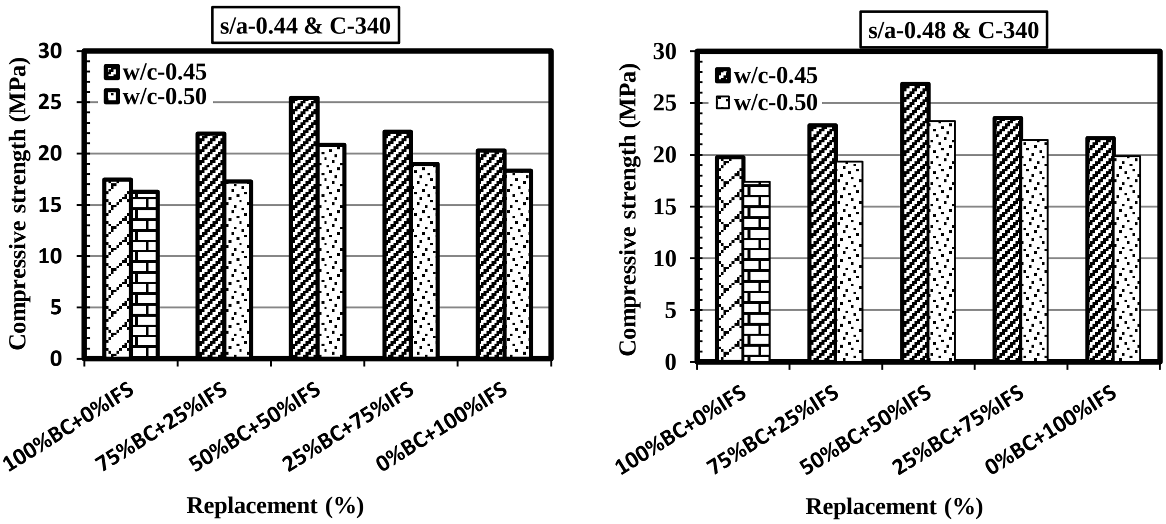

Figure 3. 28 days compressive strength of concrete

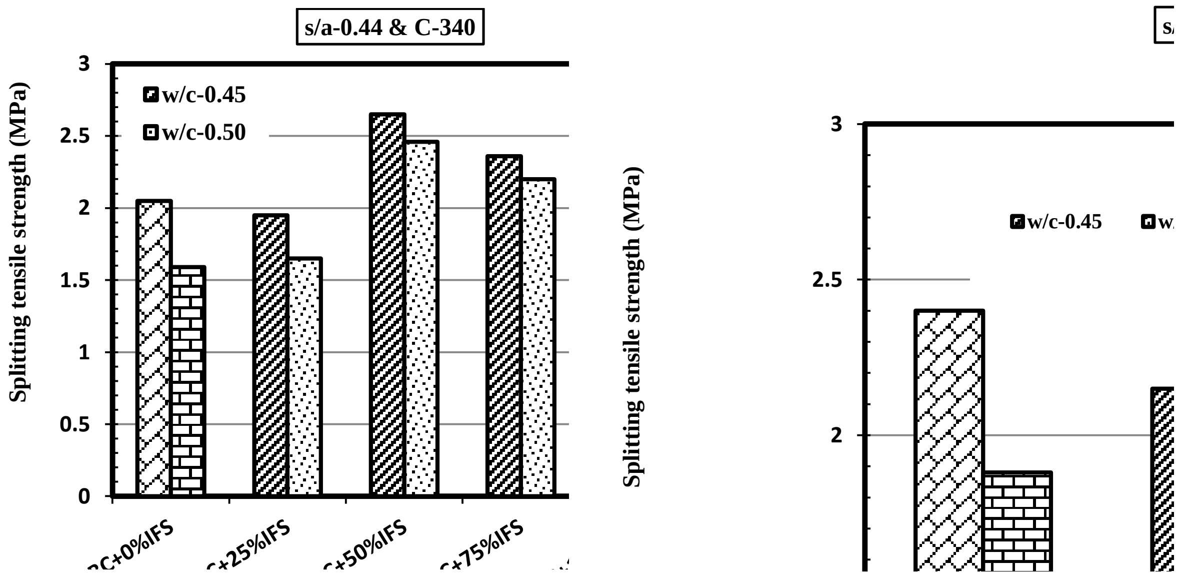

Figure 4. 28 days splitting tensile strength of concrete

3.2 Compressive Strength

The compressive strength of cylindrical concrete specimens made with different replacement ratios (0%, 25%, 50%, 75% and 100%) of brick aggregate by IFS aggregate is shown in **Figure 3**. It can be seen from **Figure 3** that compressive strength of concrete increased up to 50% replacement of BC by IFS aggregate. Beyond 50%, the compressive strength of concrete reduced but did not fall below the strength level obtained for the case of no replacement (100%BC+0%IFS). Similar results were also observed by Nadeem and Pofale (2012) and Murthi et al (2015). The increase in compressive strength can be related to the rough surface of IFS aggregate compared to the BC that would help to form a relatively stronger Interfacial Transition Zone (ITZ) around the IFS aggregate. It is also expected that at 50% replacement level, BC and IFS aggregate would produce a more compact system (amount of void in the mixture of aggregate will be the least) compared to the other replacement levels. As a result, maximum level of compressive strength of concrete was found at 50% replacement level. Irrespective of replacement level, concrete made with low W/C exhibited higher compressive strength compared to concrete made with high W/C. Using the mixture proportion as summarized in **Table 2**, it is possible to make concrete of 26 MPa and 22 MPa for W/C = 0.45 and 0.50 respectively by replacing 50% of BC with IFS aggregate.

It was found that with the increase of s/a ratio (from 0.44 to 0.48), the compressive strength of concrete increased. The reason may be attributed to the overall decrease in the volume of voids (in the mixture of fine and coarse aggregates) with the increase of the amount of fine aggregate. Similar results were also observed by Yang et al (2010), Mohammed and Rahman (2016), and Mohammed and Mahmood (2016). However, this study needs to be continued with further increase of sand to aggregate volume ratio (such as 0.50, 0.55 etc.).

3.3 Tensile Strength

The results of 28 days splitting tensile strength are presented in **Figure 4**. Same as compressive strength of concrete, the split tensile strength increased up to 50% replacement and then decreased with further increase of the amount of IFS aggregate. Again, the reason can be related to the improved interfacial transition zone (ITZ) around IFS aggregate. Nadeem and Pofale (2012) also observed similar results. They mentioned that excellent rugosity of slag aggregate ensures strong bonding and adhesion between aggregates and cement paste, and thereby increases the strength of concrete. It was also observed that an increase in s/a ratio resulted an increase in tensile strength which followed the trend of compressive strength as described earlier.

4. CONCLUSIONS

Based on the results obtained from this experimental work, the following conclusions are drawn:

- The absorption capacity of brick aggregate is much higher than the absorption capacity of induction furnace slag,
- The workability of concrete increases with the increase of replacement ratio of brick aggregate by induction furnace slag aggregate, and
- The optimum replacement ratio of brick aggregate by induction furnace slag aggregate for obtaining maximum compressive strength and tensile strength of concrete is found at 50%.

5. ACKNOWLEDGMENT

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