

# Investigation on Utilization of Steel Slag As Coarse Aggregate

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**ABSTRACT:** Brick industries are associated with a lot of negative environmental impacts including air pollution and loss of fertile land. To overcome this problem, we need to focus on alternative building materials. Therefore, this investigation was carried out to explore the possibility of utilization of steel slag in concrete as coarse aggregate. The aggregates were tested for different physical and mechanical properties. Cylindrical concrete specimens (100 mm by 200 mm) were also made with different W/C ratios and sand to aggregate volume ratios. Brick aggregate was partially (50%) /fully (100%) replaced by steel slag. The concrete specimens were tested at 7, 28 and 90 days. Also, ultrasonic pulse velocity (UPV) was measured prior to crushing of specimens. Results show that the compressive strength of concrete increases by 50% partial replacement of brick chips by steel slag. Thus, utilization of steel slag will help towards sustainable development of construction materials in Bangladesh.

**KEYWORDS:** Concrete, Steel slag, Compressive strength, Sand to aggregate volume ratio, UPV.

## I. INTRODUCTION

Concrete is the mostly used construction material in the world. Aggregates are the major constituents of concrete where coarse aggregates occupy almost half its volume. As Bangladesh is urbanizing rapidly, the demand for coarse aggregates in the construction industry is increasing rapidly. Bangladesh has very low availability of natural stones and thus needs to import them from India or other countries. Brick aggregate is found as the major building material for the country's construction industry. There are about 8000 brick kilns in operation, producing about 17.5 billion bricks per year [1] but brick industries are associated with a lot of negative environmental impact. Thus, it is necessary to find possible alternative resources which can be used as coarse aggregate in construction works. An extensive study on the recycling of demolished brick concrete as coarse aggregate was carried out for the sustainable use of construction materials in Bangladesh [2]. Other investigations of possible alternatives, such as steel slag may be conducted.

In Bangladesh the total production of steel is estimated at 8 million tons per annum and production of slag is about 1, 20,000 to 1, 60,000 metric tons per annum [3]. To utilize this large amount of steel slag in Bangladesh, it is necessary to investigate the possibility of using this by product as coarse aggregate in concrete. During production of steel, a significant portion of by-product (5-6% of total weight of steel production) is produced and these are classified as furnace slag (produced during melting of scrap and sponge iron and it becomes in lumped form after cooling in a slag pot, it is rich in silicon oxide, iron oxide and manganese oxide), process slag (produced in ladle refining furnace where CaO and other necessary ingredients are added to fix required chemical parameters of steel, it is produced in finer form and rich in calcium oxide, silicon oxide, magnesium oxide and iron oxide) and flue dust (collected from the smoke generated during melting of scrap and sponge in blast furnace, it is rich in carbon and zinc). The furnace slag can be used as coarse aggregate for making concrete as well as aggregate in asphalt paving roads. No investigation on utilization of furnace slag as coarse aggregate in concrete has been carried out yet in Bangladesh as a replacement of brick coarse aggregate. Therefore, this study has been planned to find out the suitability of utilization of the slag aggregates in concrete as coarse aggregate.

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## II. RELATED WORK

Literature survey was done to elaborate the increasing demand of coarse aggregates and represent the facts that are responsible for the search of alternative materials. Here, a brief comparison is being carried out between steel slag and brick aggregate by doing partial replacement of these constituents in concrete and see if coarse aggregate can be replaced by steel slag.

1. Since aggregates occupy 70-80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable according to authors in [4].
2. The steel slag was used as coarse aggregates in concrete and comparison was made with crushed gravel by [5]. The results showed that the compressive and flexural strength of slag concrete was slightly higher than the natural gravel concrete.
3. The mechanical strength of steel slag concrete is acceptable; though slightly lower flexural strength than that of conventional concrete. The expansion induced from steel slag using as coarse aggregates in concrete may lower the shrinkage and expansion to a certain extent was concluded by [6].
4. Authors in [7] stated that, the s/a ratio is an important parameter and rheological properties such as, the compressive and tensile strength of concrete increase with an increase in the s/a ratio.
5. Authors in [8] investigated the influence of aggregate grading and w/c ratio on the workability and compressive strength of mortar. Authors observed that increase in w/c ratio has reduced the value of mechanical properties and increased the workability.
6. UPV measurements were conducted on concrete specimens to gauge the internal structure of the specimen. Authors in [9] concluded that higher or faster levels of velocity indicate higher density, integrity, and quality of the material.

## III. METHODOLOGY

The slag aggregate was collected from a local steel manufacturing company. It was found that some slag aggregate was light in weight with a lot of voids and some were heavier with little or no voids. Therefore, the slag aggregates were termed as the mixed slag aggregate (SM). The slag aggregate was tested for grading, unit weight, abrasion, specific gravity and absorption capacity and abrasion as per ASTM standards. Different types of aggregates investigated in this study are shown in Figure 1. Natural river sand was used as fine aggregate. The physical properties of coarse and fine aggregates are summarized in the Table 1.

Table 1: Physical properties of coarse and fine aggregates

Type of Aggregate	Specific Gravity	Absorption Capacity (%)	SSD Unit Weight (kg/m <sup>3</sup> )	Abrasion (%)	FM
BC (Brick Chips)	2.14	19	1211	38.8	Controlled as per ASTM-C33
SM (Slag-Mixed)	2.65	2.62	1550	35.2	
Fine Aggregate (Sylhet Sand)	2.59	3.30	1520	-	

Table 1 contains the list of results obtained from a number of material tests conducted on the coarse and fine aggregates according to ASTM, prior to conducting all the destructive and non-destructive tests. The results obtained show material quality and help calculate the material proportions required according to mix design.

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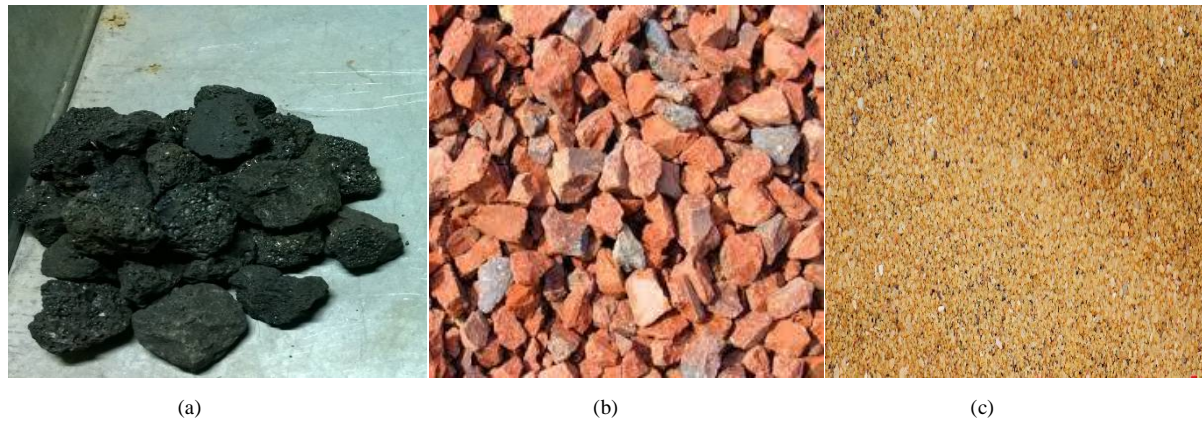


Fig. 1. Different Types of Aggregates (a) Mixed Slag (b) Brick Chips (c) Sylhet Sand

Figure 1 shows all the different aggregates used in the concrete mixture. The mixed steel slag broken and sieved according to ASTM is at the left-hand side, the natural coarse aggregates which are the broken brick chips are at the center and the natural fine aggregates sieved and prepared according to ASTM are at the right-hand side.

The grading curves of coarse and fine aggregates satisfy the requirement of ASTM C33 as shown in Figure 2. 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. 100 mm by 200 mm cylindrical concrete specimens were made with a varying s/a ratio (0.40, 0.44, and 0.48); W/C ratio (0.45 and 0.50), and cement content of  $340 \text{ kg/m}^3$ . Total 18 independent cases were investigated. A total of 198 cylindrical specimens were made. The mixture proportions are summarized in Table 2 for each different replacement ratios (0%, 50% and 100%) to achieve a compressive strength higher than the conventional concrete mixes.

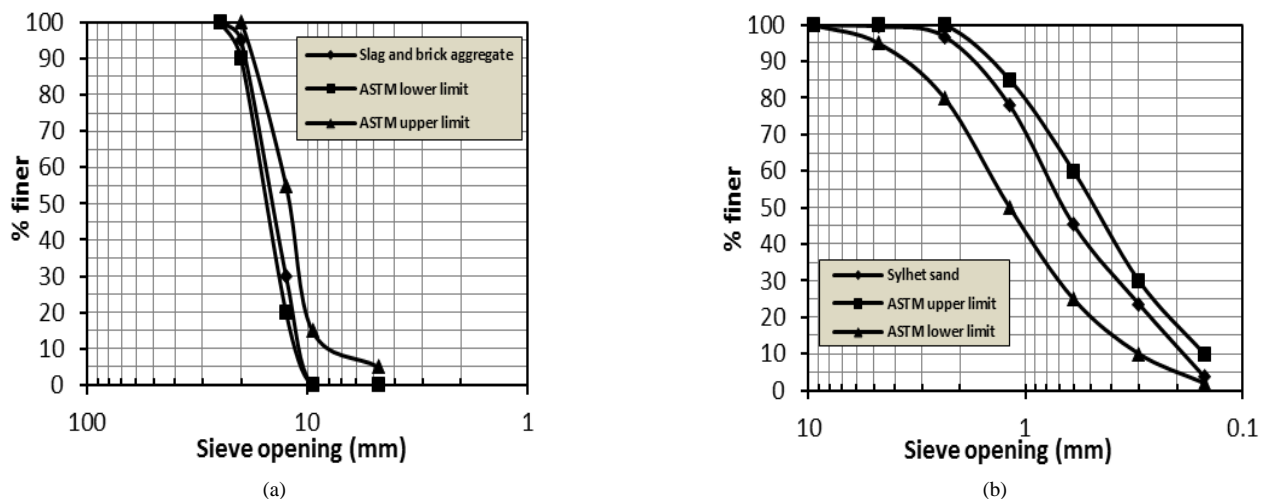


Fig. 2. Grading Curve of Aggregates (a) Coarse Aggregates (b) Fine Aggregate

Figure 2 shows the grading curves of both the coarse and fine aggregates and we can observe that both our curves pass in between the lower limit and upper limit set according to the ASTM.

After mixing concrete, slump was measured and then concrete specimens were made as per ASTM C31M-03. The

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specimens were cured under water till the testing for compressive strength. Before crushing of the specimen ultrasonic pulse velocity (UPV) was measured by using Pundit (UPV meter) according to ASTM C 597-02. The specimens were then crushed by a compression machine. They were tested at 7, 28 and 90 days.

Table 2: Mixture Proportion of Concrete

% Replacement of Coarse Aggregate	Cement content (kg/ m <sup>3</sup> )	s/a	W/C	Unit Content,(kg/m <sup>3</sup> )					No. of Cylinders
				Cement	Fine Aggregate	Water	Coarse Aggregate		
							Slag	Brick	
100% slag + 0% brick	340	0.40	0.45	340	735	153	1129	0	18*11=198
			0.50	340	718	170	1101	0	
		0.44	0.45	340	808.84	153	1053	0	
			0.50	340	789.46	170	1028	0	
		0.48	0.45	340	882.3	153	978	0	
			0.50	340	861.23	170	954.6	0	
50% slag + 50% brick	340	0.40	0.45	340	735	153	564	455.7	
			0.50	340	718	170	550.7	444.8	
		0.44	0.45	340	808.84	153	526.6	425.3	
			0.50	340	789.46	170	514	415.1	
		0.48	0.45	340	882.3	153	489	394.9	
			0.50	340	861.23	170	477.3	385.5	
0% slag + 100% brick	340	0.40	0.45	340	735	153	0	911.3	
			0.50	340	718	170	0	889.5	
		0.44	0.45	340	808.84	153	0	850.6	
			0.50	340	789.46	170	0	830.2	
		0.48	0.45	340	882.3	153	0	789.8	
			0.50	340	861.23	170	0	770.09	

Table 2 shows the different mixture proportions of concrete. The different amount of aggregates required for different partial replacement of coarse aggregates along with different s/a and W/C ratio were calculated according to mix design prior to casting of the concrete cylinders

### IV. RESULTS AND DISCUSSION

#### III.I Workability of concrete

It is found that with the increase of s/a ratio, workability is reduced. It is clearly revealed that the concrete made with slag aggregate has better workability compared to the similar concrete made with brick aggregate. Author in [10] also concluded that the use of steel slag as replacement of coarse aggregate in concrete is beneficial for the better workability and strength up to 50% replacement level.

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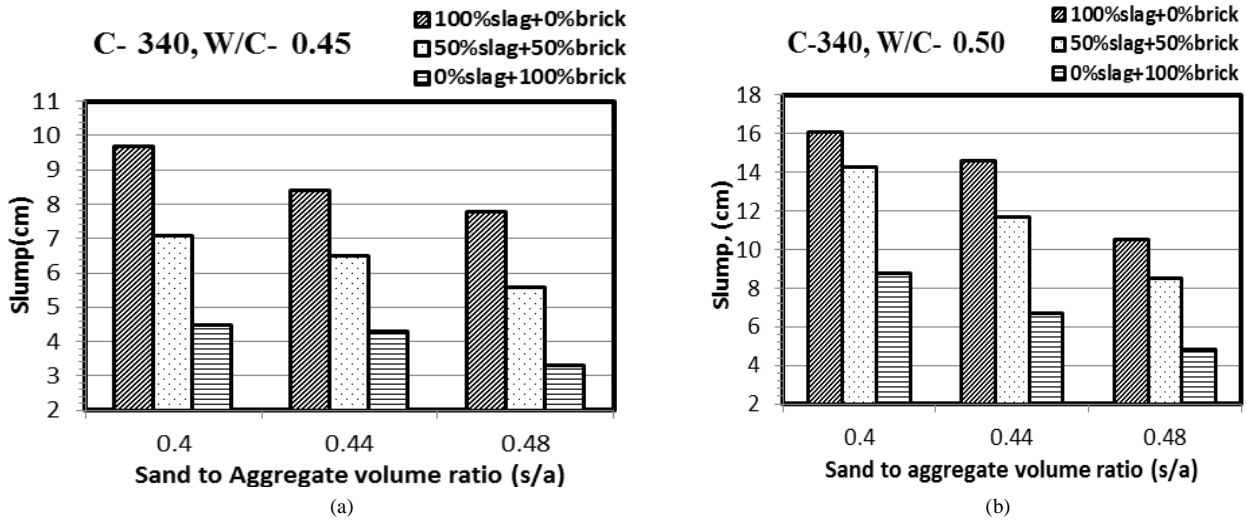


Fig. 3. Workability of Concrete (Left-W/C-0.45 and Right- W/C-0.50)

Figure 3 shows the workability of concrete as slump (in cm) for W/C 0.45 and 0.50. It is found that W/C of 0.50 shows better slump than the W/C ratio of 0.45. On the other hand, with the increase of replacement ratio of steel slag the workability increases. It is clearly found that concrete made with a 100% slag aggregate shows maximum workability. This is expected due to the less water absorption capacity of slag aggregate compared to the brick aggregate.

### III.II Compressive strength

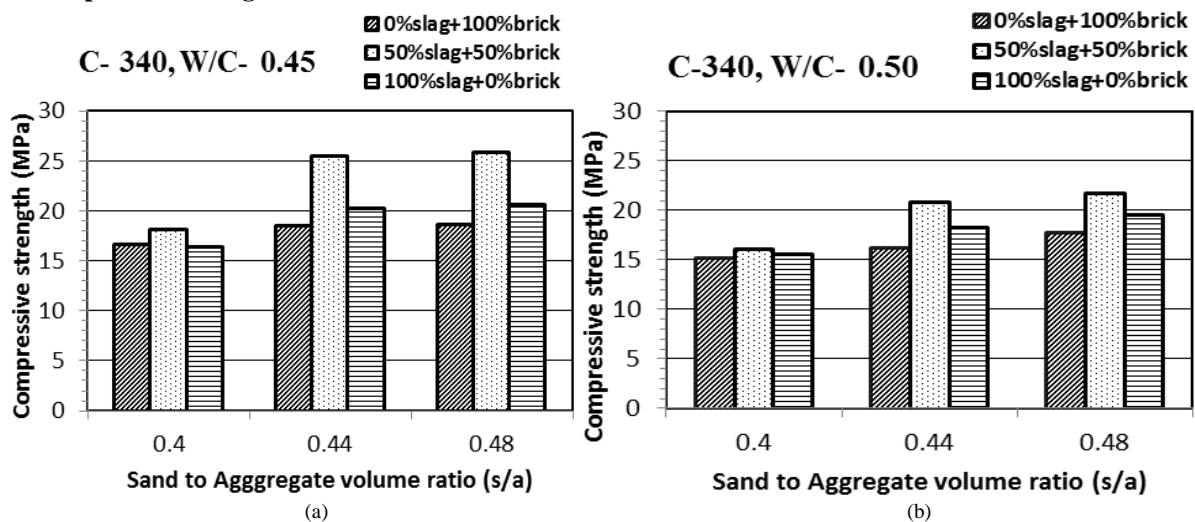


Fig. 4. Compressive Strength of concrete (a) W/C-0.45 (b) W/C-0.50)

Figure 4 shows the 28 day compressive strengths of concrete cylinders for 0%, 50% and 100% replacement ratios of steel slag. From the Figure, it is found that for 50% replacement of steel slag the strength increases but after that the strength decreases. For 50% replacement of steel slag, the compressive strength of concrete is found 26 Mpa and 22 Mpa for W/C 0.45 and 0.50 respectively. This indicates, with the increase of W/C ratio the compressive strength tends to decrease.



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Another observation is that with the increase of s/a ratio the compressive strength of concrete is increased. It is found that the compressive strength is highest at 50% replacement of steel slag for each s/a ratio. The improvement in strength may be due to shape, size and surface texture of steel slag aggregates, which provide better bonding between the particles and cement paste [10].

### III.III Tensile Strength

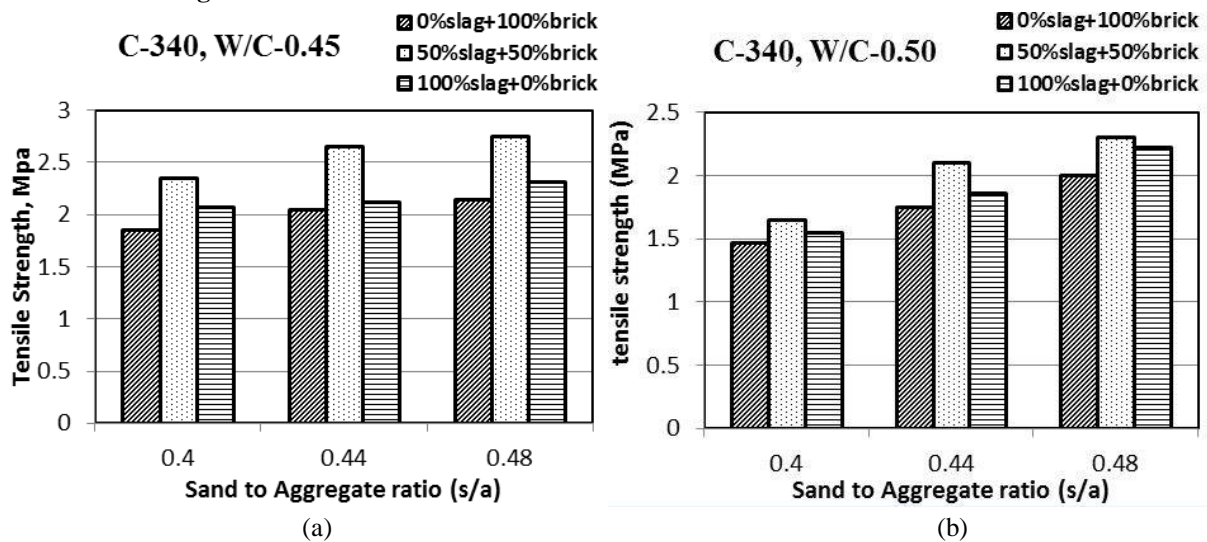


Fig. 5. Tensile Strength of concrete (a) W/C-0.45(b) W/C-0.50

Figure 5, shows the split tensile strength of concrete using steel slag at 28<sup>th</sup> days. The results show that the split tensile strength is increased up to 50% replacement of coarse aggregate with steel slag, beyond that the split tensile strength decreases.

The replacement of coarse aggregate with steel slag has increased the compressive strength and split tensile strength of concrete [10]. It is also observed that the tensile strength follows the trend of compressive strength as described earlier.

### III.IV Ultrasonic Pulse Velocity (UPV)

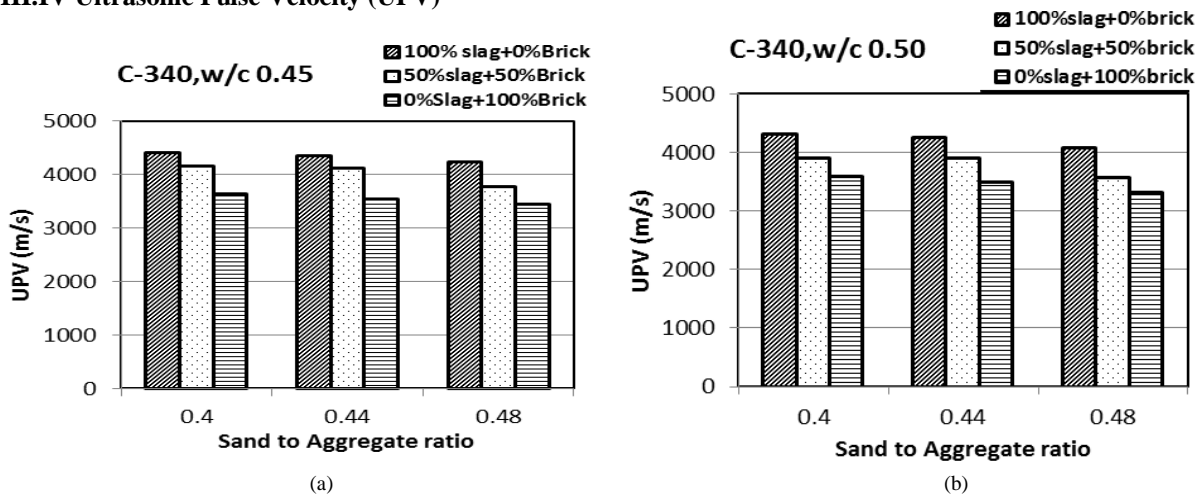


Fig. 6. Ultrasonic pulse velocity (a) W/C-0.45 (b) W/C-0.50

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Figure 6 shows the variation of UPV with the change of different s/a ratio, W/C ratio and other parameters. It is observed that the lower W/C ratio gives better pulse velocity than a higher W/C ratio but with increasing s/a ratio, the strength tends to increase despite the UPV of concrete decreasing.

The concrete strength is inversely proportional to water to cement ratio [11]. So with the increase of w/c the UPV of concrete tends to decrease. On the other hand, with the increase of partial replacement of brick chips by steel slag the UPV also increases. This is because, steel slag has high iron content making the ultrasonic pulse travel faster than anticipated.

### V. CONCLUSION

From the extensive experimental investigation carried out on partial replacement of brick chips in concrete by steel slag, the following conclusions are drawn:

1. Steel slag in aggregate show better workability than brick chips aggregates.
2. 50% of brick aggregate can be replaced by steel slag aggregate without reduction in strength.

### VI. ACKNOWLEDGMENT

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