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BRICK FINE AGGREGATE AND LADLE FURNACE SLAG AS ALTERNATIVE TO NATURAL RIVER SAND

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ABSTRACT

An experimental investigation was carried out to explore the possibility of utilizing brick fine aggregate (BFA) and ladle furnace slag (LFS) as alternative to natural river sand as fine aggregates in concrete. For this, cylindrical concrete specimens of 100 mm x 200 mm size were made by varying the replacement ratios of natural river sand to the alternative fine aggregates, W/C ratios, and fine aggregate-to-total aggregate (f/a) volume ratios. Workability of concrete was measured by slump cone test. The concrete specimens were cured under water and tested at 28 days for compressive strength, tensile strength, and modulus of elasticity of concrete.

From the experimental results, it was observed that BFA absorbs more water compared to natural river sand and LFS. With the increasing replacement ratios of the alternative fine aggregates, the workability of concrete increased for the concrete made with LFS but decreased for the concrete made with BFA. Compressive strength of concrete increased with the increased replacement of natural river sand by BFA and LFS up to 30% and 20% replacement ratios respectively. The trend of tensile strength and modulus of elasticity of concrete were found similar to that of the compressive strength of concrete. It was concluded that it is possible to utilize BFA and LFS as alternative fine aggregates to natural river sand in concrete without reducing the compressive strength of concrete for up to 30% and 20% replacement ratios respectively. Utilization of BFA and LFS as fine aggregates will reduce the demand of natural river sand in the construction works and may help toward achieving the sustainability of construction materials in Bangladesh.

Keywords: Brick, Ladle Furnace Slag, Fine Aggregate, Compressive Strength, Tensile Strength, Workability, Modulus of Elasticity.

INTRODUCTION

Bangladesh is a plain and delta land which has very limited sources for coarse aggregate and fine aggregate to make concrete. Due to the lack of availability of stone aggregate, clay bricks are widely used to make coarse aggregate which has tremendous input to environmental pollution. Natural river sand is mainly used as fine aggregate in concrete, which is mostly extracted from the riverbed by dredging. Due to huge construction works related to several mega projects as well as small scaled government and private projects, it is expected that in the very near future, there will be a significant amount of depletion of natural fine aggregate.

Therefore, it becomes essential to explore possible alternative fine aggregates for the sustainable development of construction materials. As alternative to natural river, brick fine aggregate (locally known as surki) may be used as fine aggregate in concrete. There are more than 6000 brick industries in Bangladesh due to the high demand of bricks as construction material. Crushing of these bricks in the construction sites produces a significant amount of fine materials which are not utilized in most cases. Although many attempts were made in order to understand the suitability of crushed brick chips as coarse aggregate in concrete, very few studies were found with brick fine aggregate in concrete (Akhtaruzzaman and Hasnat, 1986, 1983; Bektas et al., 2009; Cachim, 2009; Debieb and Kenai, 2008; Mohammed et al., 2015; Mohammed and Hassan, 2015; Mohammed and Mahmood, 2016). Therefore, a thorough investigation is necessary to understand the suitability of brick fine aggregate as fine aggregate in concrete.

Currently, the annual production of steel in Bangladesh has raised to about 3 million Metric Tons. The steel industries in Bangladesh commonly use induction furnaces for rerolling of steel and ladle refined furnaces are used for refining of molten steel producing the amorphous ladle furnace slag or LFS as a by-product. An attempt was made to investigate the possibility of utilization of induction furnace slag as coarse aggregate in concrete (Mohammed et al., 2016). Many researchers had studied the suitability of incorporating fine slag as fine aggregate in concrete (Kockal, 2016; Pellegrino et al., 2013). However, few literatures were found where the suitability of ladle furnace slag as fine aggregate in concrete was discussed (Adolfsson et al., 2011; John and John, 2013). Therefore, further investigations are necessary in order to understand the suitability of LFS as fine aggregate in concrete.

With the above-mentioned background, a detailed experimental investigation was carried out by replacing natural river sand with BFA , and LFS by varying replacement ratio (0~50% for BFS and 0~30% for LFS), , W/C (0.5 and 0.55), sand-to-aggregate volume ratio (f/a) (0.44 and 0.48), etc. The results will be useful to understand the possibility of replacing natural river sand by these alternative by-product materials.

EXPERIMENTAL METHOD

Fine aggregates investigated in this study include brick fine aggregate (BFA) and ladle refined furnace slag (LFS) aggregate as shown in **Fig. 1**. Brick fine aggregate (BFA) samples were collected from three different sources of brick aggregate (denoted as S1, S2, and S3) where the crushing of brick produced BFA as a by-product of brick coarse aggregate. The slags used in this study were collected from a local steel manufacturing company where selected ferrous scraps are used to produce steel-based products. Scraps are melted in the induction furnace. Slag is removed from the furnace at regular intervals. This slag is often termed as induction furnace slag (IFS). The molten metal is transferred into a ladle refined furnace to facilitate refinement of the metal. Fine slag collected from the ladle refined furnace is often called as ladle furnace slag or LFS.

Natural river sand was used as the controlled fine aggregate for comparison with different alternatives. The fine aggregates were tested for specific gravity, absorption capacity, fineness modulus, and SSD unit weight as per ASTM specifications. The coarse aggregates were also tested for specific gravity, absorption capacity, fineness modulus, SSD unit weight, and abrasion as per ASTM specifications. The physical properties of coarse and fine aggregates are summarized in **Table 1** and **Table 2** respectively. The maximum size of coarse aggregate was 19 mm. The grading of coarse aggregates was controlled as per the requirement of ASTM C33 as shown in **Fig. 2a**. The brick fine aggregate sample, BFA (S-1) was relatively coarser compared to the ASTM specifications. The fine aggregate sample, LFS was relatively finer compared to the ASTM specifications. CEM type II/B-M (as per BDS EN197–1:2000) was used which consists of 65-79% clinker and 21-35% of mineral admixture and gypsum.

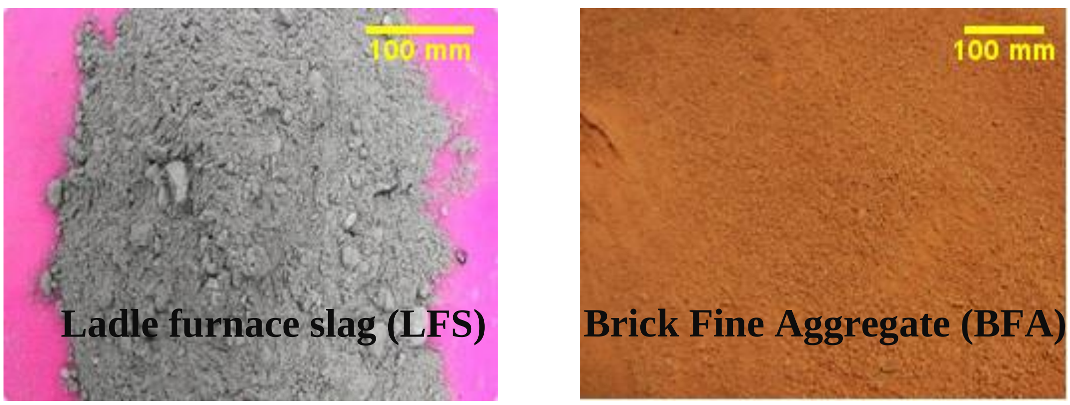


Fig. 1. Fine aggregates investigated in this study

Table 1. Physical properties of coarse aggregates investigated

Type of coarse aggregate	Fineness modulus (FM)	% Wear	Bulk specific gravity in SSD condition	Absorption capacity (%)	Unit weight (kg/m^3)
Brick Aggregate (BA), S1	Controlled as per ASTM C33	35.0	1.7	13.1	1125
Brick Aggregate (BA), S2		33.0	1.9	15.7	1351
Brick Aggregate (BA), S3		30.0	2.1	11.1	1170
Brick Aggregate (used with LFS fine slag)		34.1	2.15	19.0	1214

Table 2. Physical properties of fine aggregates investigated

Type of fine aggregate	Fineness modulus (FM)	Bulk specific gravity in SSD condition	Absorption capacity (%)	Unit weight (kg/m^3)
Natural River Sand (SS)	2.55	2.55	5.1	1497
Brick Fine Aggregate (BFA), S1	3.90	2.10	13.5	1322
Brick Fine Aggregate (BFA), S2	3.20	2.20	15.0	1211
Brick Fine Aggregate (BFA), S3	2.70	2.10	11.0	1615
Ladle Furnace Slag (LFS)	2.36	2.61	2.7	1400

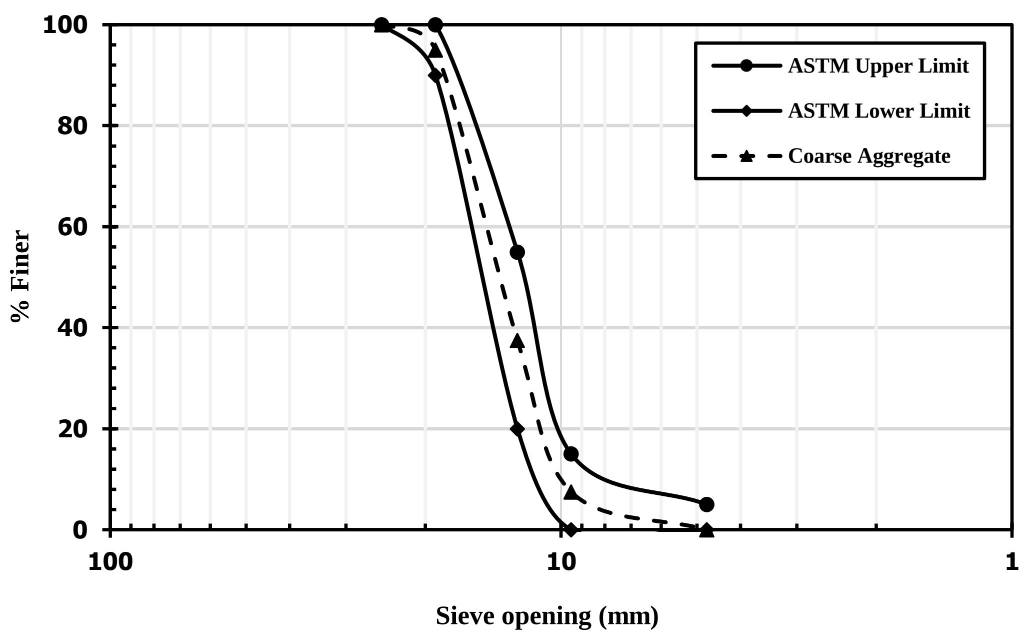


Fig. 2a. Gradation of coarse aggregate.

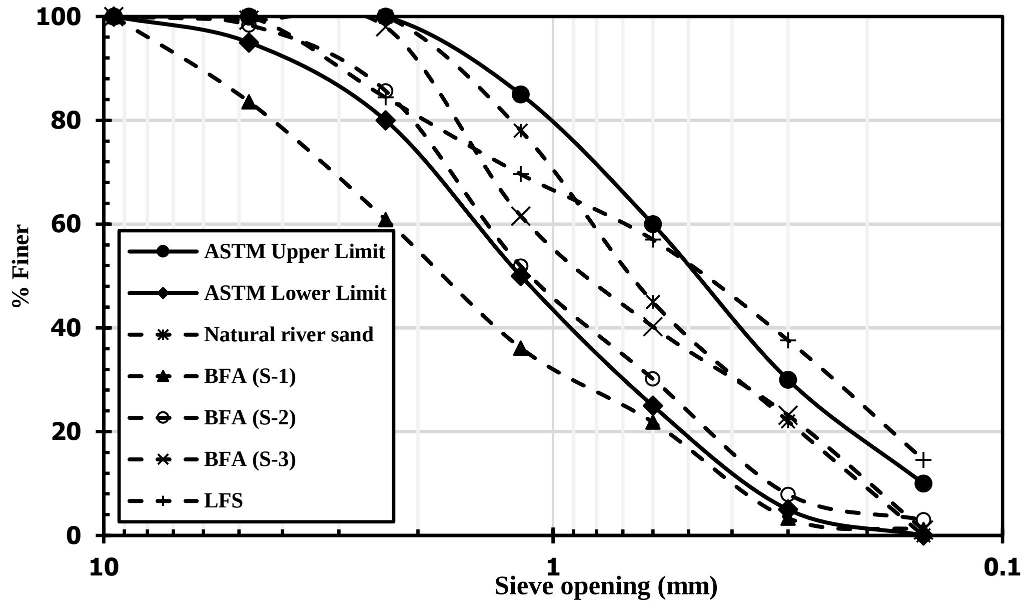


Fig. 2b. Gradation of fine aggregate.

To investigate the effect of BFA in concrete, 100 mm x 200 mm cylindrical concrete specimens were made by incorporating 0%, 10%, 20%, 30%, 40%, and 50% brick fine aggregate as a replacement of natural river sand where fine aggregate-to-total aggregate (f/a) volume ratio was 0.40, water to cement (W/C) ratio were 0.50 and 0.55, and cement content was fixed at 340 kg/m^3 for all the cases. Brick coarse aggregates from the respective sources (S1, S2, S3) of BFA were used as coarse aggregate in making concrete. Cases investigated for all concrete specimens made with BFA are summarized in **Table 3**. Concrete specimens were also made by replacing natural sand with ladle refined furnace slag at 0%, 10%, 20% and 30% replacement ratios with fine aggregate-to-total aggregate (f/a) volume ratios of 0.40 and 0.48, water to cement (W/C) ratios of 0.45, and cement contents of 340 kg/m^3. Brick coarse aggregate was used as coarse aggregates in concrete. All the cases investigated for concrete specimens made with LFS are summarized in **Table 4**.

The concrete specimens were casted in steel molds and kept under a humid environment for 24 h. The specimens were demolded after 24 h of casting and kept underwater till the age of testing. The concrete specimens were tested for compressive strength, tensile strength, and modulus of elasticity at the age of 28 days as per ASTM specifications.

RESULTS AND DISCUSSION

Physical Properties of Alternative Aggregates

It can be observed from Table 1 that the specific gravity of ladle furnace slag (LFS) was the highest (2.61) among the fine aggregates investigated. Regardless of the sources, the specific gravity of brick fine aggregates (BFA) used in this study were found to be almost similar. In terms of absorption capacity, the fine aggregates can be ordered as BFA > natural river sand > LFS. It can be observed from the Fig. 2b that the gradation curve of BFA (S1) lies under the ASTM lower limit, which indicates that the aggregate is substantially coarser than the other fine aggregates investigated. In case of ladle furnace slag, it is observed from Fig. 2b that the finer portion of their gradation curves lies above the ASTM upper limit indicating that they are substantially finer compared to other fine aggregates investigated in this study.

Workability of Concrete

The workability of concrete made with brick fine aggregate collected from different sources (S1, S2, S3) is shown in **Fig. 3**. It is observed from the figure that the workability of concrete reduced with the increase of replacement ratios of brick fine aggregate. This is because brick fine aggregates had more absorption capacity compared to natural river sand. Also, the brick fine aggregate is angular in shape where the natural rive sand is a round shaped fine aggregate.

The workability of concrete prepared with 0%, 10%, 20% and 30% replacements of river sand by LFS aggregate are presented in **Fig. 4**. The results show that the workability of concrete is reduced with the increase of percentage replacement of river sand by LFS. The workability of concrete is increased for a small amount of replacement however it reduces for the higher amount of replacements. The reason behind initial increase in workability may be attributed to the low absorption capacity of LFS aggregate (as shown in **Table 2**). Beyond 10% replacement, the workability reduced as LFS aggregate contains more fine particles compared to river sand (**Fig. 2b**). Moreover, LFS particles are more angular in shape in comparison to river sand particles, which may be attributed to concrete exhibiting low workability beyond 10% replacement of river sand by LFS aggregate. For f/a = 0.48, brick aggregate concrete resulted in almost zero slump beyond 30% replacement of river sand by LFS. Therefore, the scope of this study was kept limited to 30% replacement of river sand by LFS aggregate. Nevertheless, studies may still be planned to investigate replacements greater than 30% by improving workability of fresh concrete using high range water reducers.

Table 3. Mix proportions of concrete specimens made with brick fine aggregate

<table>
<tr><th rowspan="3">Sources of Brick Sample</th><th colspan="2" rowspan="2">Replacement (%)</th><th rowspan="3">W/C</th><th rowspan="3">f/a</th><th colspan="5">Mix proportions, kg/m³</th><th rowspan="3">Unit Weight of fresh concrete (kg/m³)</th><th rowspan="3">28-day comp. strength (MPa)</th></tr>
<tr><th rowspan="2">Cement</th><th rowspan="2">Water</th><th rowspan="2">Coarse aggregate</th><th colspan="2">Fine Aggregate</th></tr>
<tr><th>Natural River Sand</th><th>Brick Fine Aggregate</th><th>Natural River Sand</th><th>Brick Fine Aggregate</th></tr>
<tr><td rowspan="12">S1</td><td>100</td><td>0</td><td rowspan="6">0.5</td><td rowspan="12">0.4</td><td rowspan="12">340</td><td rowspan="6">170</td><td rowspan="6">706</td><td>0</td><td>1081</td><td>1957</td><td>24.29</td></tr>
<tr><td>90</td><td>10</td><td>71</td><td>973</td><td>1920</td><td>28.88</td></tr>
<tr><td>80</td><td>20</td><td>141</td><td>865</td><td>1882</td><td>28.40</td></tr>
<tr><td>70</td><td>30</td><td>212</td><td>757</td><td>1845</td><td>30.42</td></tr>
<tr><td>60</td><td>40</td><td>283</td><td>648</td><td>1807</td><td>21.92</td></tr>
<tr><td>50</td><td>50</td><td>353</td><td>540</td><td>1769</td><td>20.35</td></tr>
<tr><td>100</td><td>0</td><td rowspan="6">0.55</td><td rowspan="6">187</td><td rowspan="6">689</td><td>0</td><td>1054</td><td>1930</td><td>23.29</td></tr>
<tr><td>90</td><td>10</td><td>69</td><td>948</td><td>1893</td><td>23.65</td></tr>
<tr><td>80</td><td>20</td><td>138</td><td>843</td><td>1857</td><td>24.71</td></tr>
<tr><td>70</td><td>30</td><td>207</td><td>738</td><td>1821</td><td>25.16</td></tr>
<tr><td>60</td><td>40</td><td>276</td><td>633</td><td>1785</td><td>20.34</td></tr>
<tr><td>50</td><td>50</td><td>345</td><td>527</td><td>1748</td><td>18.14</td></tr>
</table>

S2	100	0	0.5			170	831	0	887	1888	26.87
	90	10						71	798	1870	28.16
	80	20						141	709	1851	28.30
	70	30						212	621	1834	29.91
	60	40						283	532	1816	24.05
	50	50						353	443	1797	20.20
	100	0	0.55			187	811	0	865	1863	26.87
	90	10						71	778	1847	27.86
	80	20						141	692	1831	28.62
	70	30						212	606	1816	25.19
	60	40						283	519	1800	18.90
	50	50						353	432	1783	18.98
S3	100	0	0.5			170	873	0	748	1791	26.49
	90	10						71	673	1787	28.45
	80	20						141	598	1782	28.55
	70	30						212	524	1779	29.71
	60	40						283	449	1775	20.67
	50	50						353	374	1770	20.33
	100	0	0.55			187	851	0	730	1768	20.96
	90	10						71	657	1766	22.86
	80	20						141	584	1763	23.01
	70	30						212	511	1761	24.80
	60	40						283	438	1759	19.54
	50	50						353	365	1756	18.88

Table 4. Mix proportions of concrete specimens made with ladle furnace slag aggregate.

Replacement (%)		W/C	f/a	Mix proportions, kg/m^3					Unit Weight of fresh concrete (kg/m^3)	28-day comp. strength (MPa)
				Cement	Water	Fine aggregate		Coarse aggregate		
Natural River sand	LFS					River sand	LFS			
100	0	0.45	0.44	340	153	796	0	855	2144	19.8
			0.48			869	0	794	2156	21.6
90	10		0.44			717	82	855	2147	21.2

			0.48			782	89	794	2158	22.8
80	20		0.44			637	163	855	2148	22.4
			0.48			695	178	794	2160	23.6
70	30		0.44			557	245	855	2150	22.1
			0.48			608	267	794	2162	23

Compressive Strength

The 28-day compressive strength of cylindrical concrete specimens made with 0% ~ 50% replacement ratios of BFA from different sources (S1, S2, S3) is shown in **Fig. 5**. It can be observed from the figure that the compressive strength of concrete is found maximum at a replacement ratio of 30% irrespective of different W/C ratios and sources of the brick fine aggregate investigated. The brick fine aggregate also improves the compressive strength of concrete by internal curing up to 30% BFA replacement ratio. Beyond 30% BFA replacement ratio, the compressive strength of concrete started to reduce. It is due to the inadequate amount of cement paste required for lubricating the aggregates in concrete. **Fig. 5** also shows that although for W/C of 0.50 the compressive strength of concrete specimens made with 0% ~ 50% BFA replacement ratios did not show much variation in terms of the sources of brick fine aggregate, a significant amount of variation was observed in the compressive strength of concrete for W/C of 0.55. **Fig. 6** shows the 28-day compressive strength of concrete specimens made with 0%, 10%, 20% and 30% replacements of river sand by LFS fine aggregate. It is observed that compressive strength increased with the increase of percentage replacement of natural river sand by LFS up to 20% and then decreased slightly at 30% replacement ratio.

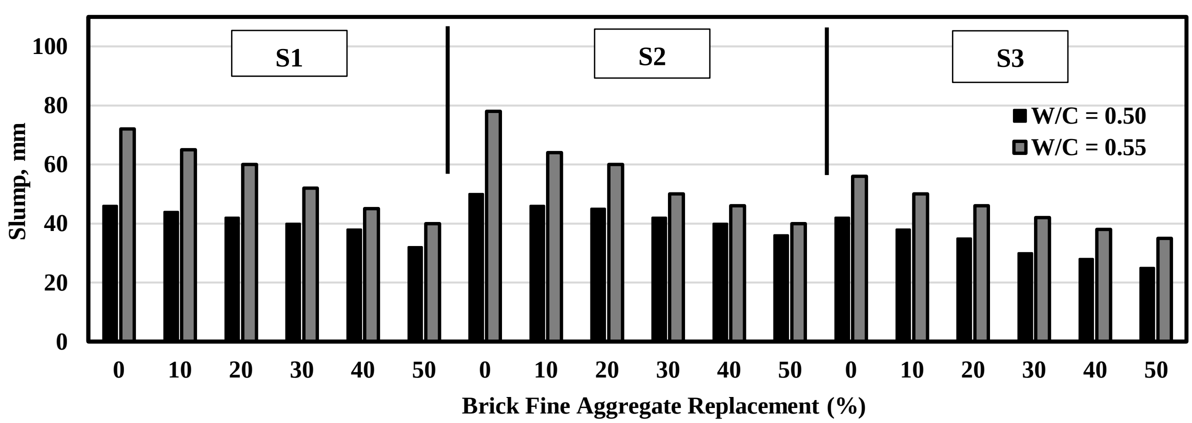


Fig. 3. Workability of concrete made with different replacement ratios of BFA.

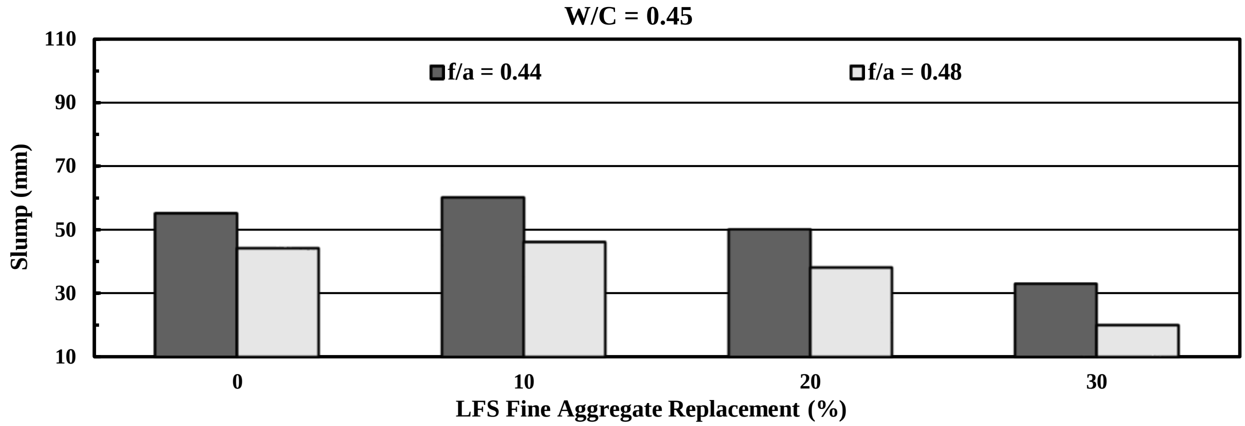


Fig. 4. Workability of concrete made with different replacement ratios of LFS.

When river sand was replaced by LFS at a percentage 20%, the high angularity of LFS aggregate led to increase the bond between LFS particles and cement paste which increased the compressive strength of concrete initially. As LFS is finer than natural sand, it also helps to fill some smaller voids and thereby increase the compressive strength of concrete. The possible reason of strength reduction beyond 20% replacement may be related to the increased amount of fine particles in concrete and the reduced workability. Since LFS contains more fines than river sand, LFS particles would require more cement to be effectively coated. Therefore, compressive strength of concrete would reduce for high percentage replacement of river sand by LFS. Again, high percentage replacement of river sand by LFS would cause substantial reduction in workability (**Fig. 4),** which would lead to formation of less dense concrete and eventually cause reduction in strength.

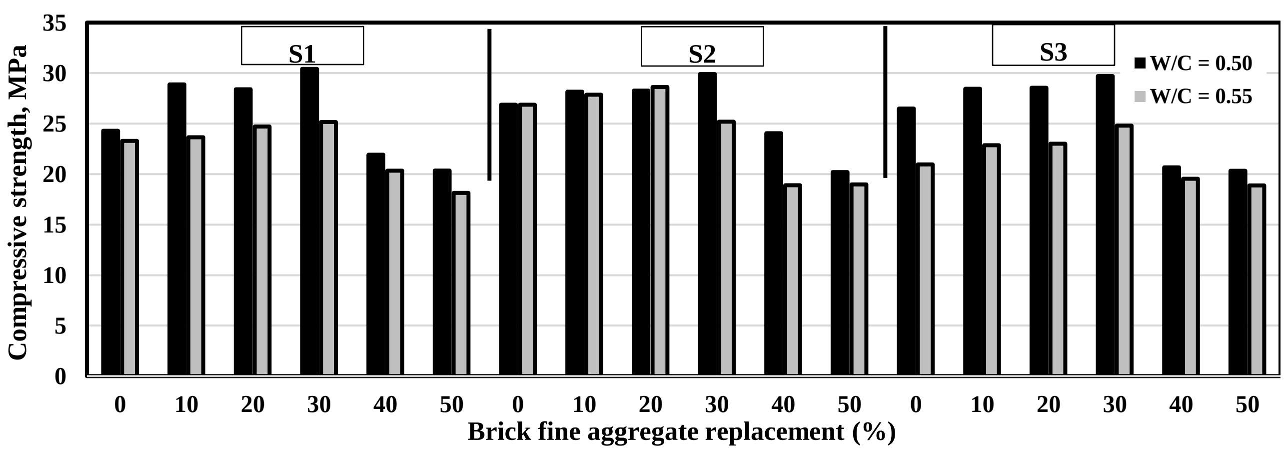


Fig. 5. Compressive strength of concrete made with 0% – 50% replacement ratios of BFA.

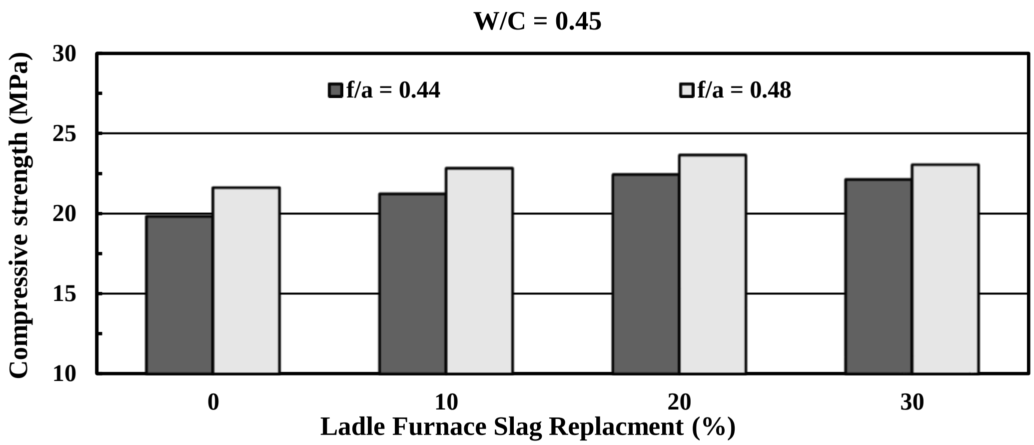
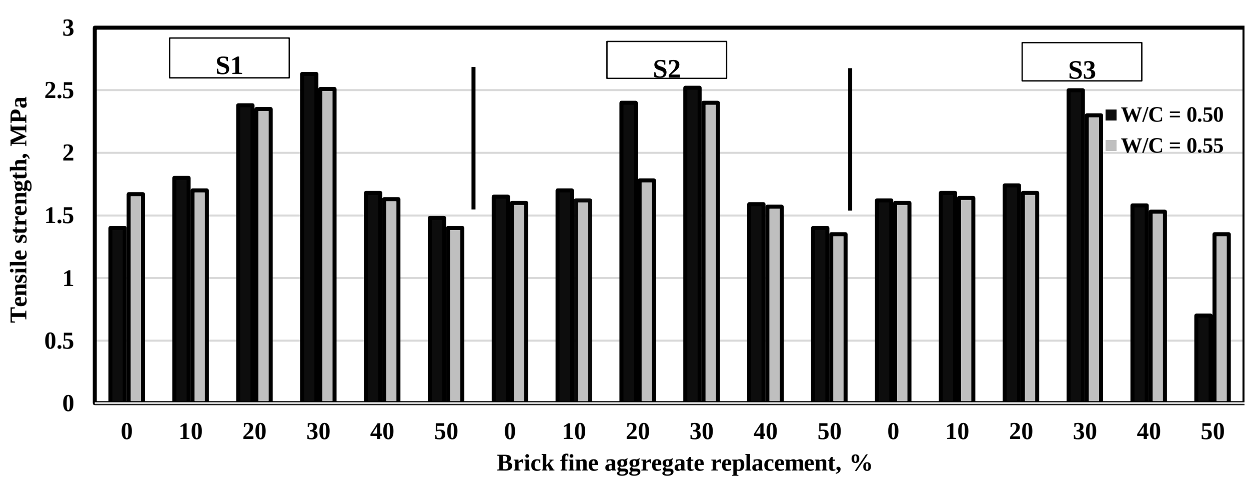


Fig. 6. Compressive strength of concrete made with 0% – 30% replacement ratios of LFS.

Tensile Strength and Modulus of Elasticity of Concrete

Fig. 7 shows the tensile strength and modulus of elasticity of concrete specimens made with brick fine aggregate for different replacement ratios. Results presented in **Fig. 7** confirm that the trend of tensile strength and modulus of elasticity of the concrete specimens are similar to that of the compressive strength of concrete made with BFA. Both optimum tensile strength and modulus of elasticity are found to be at 30% replacement ratio.

The 28-day splitting tensile strength and modulus of elasticity of concretes made with 0%, 10%, 20% and 30% replacements of river sand by LFS aggregate are shown in **Fig. 8**. Similar to the compressive strength test results shown in **Fig. 6**, the optimum tensile strength and modulus of elasticity was found at 20% replacement when brick aggregate was used as coarse aggregate.



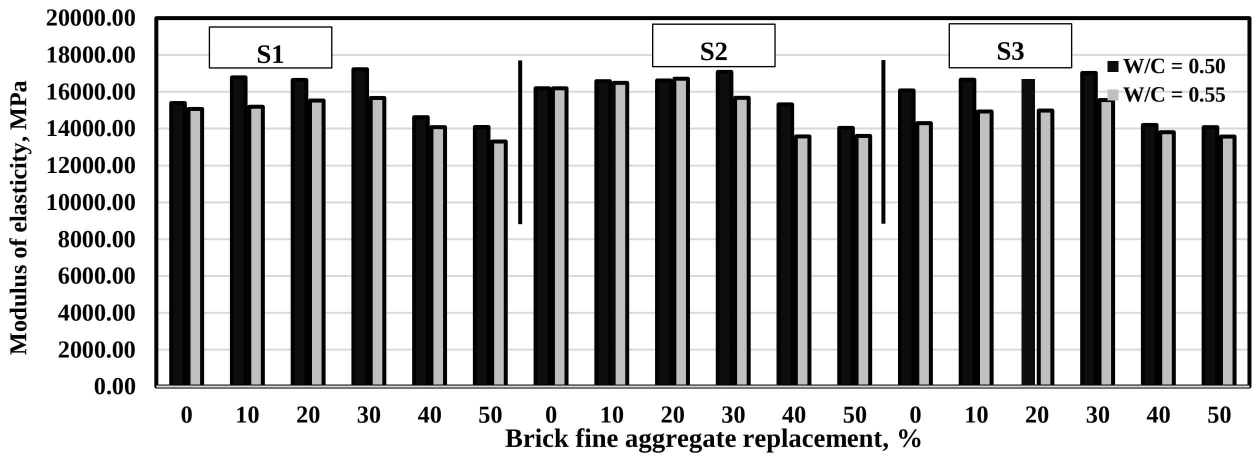


Fig. 7. 28-day tensile strength and modulus of elasticity of concretes made with BFA.

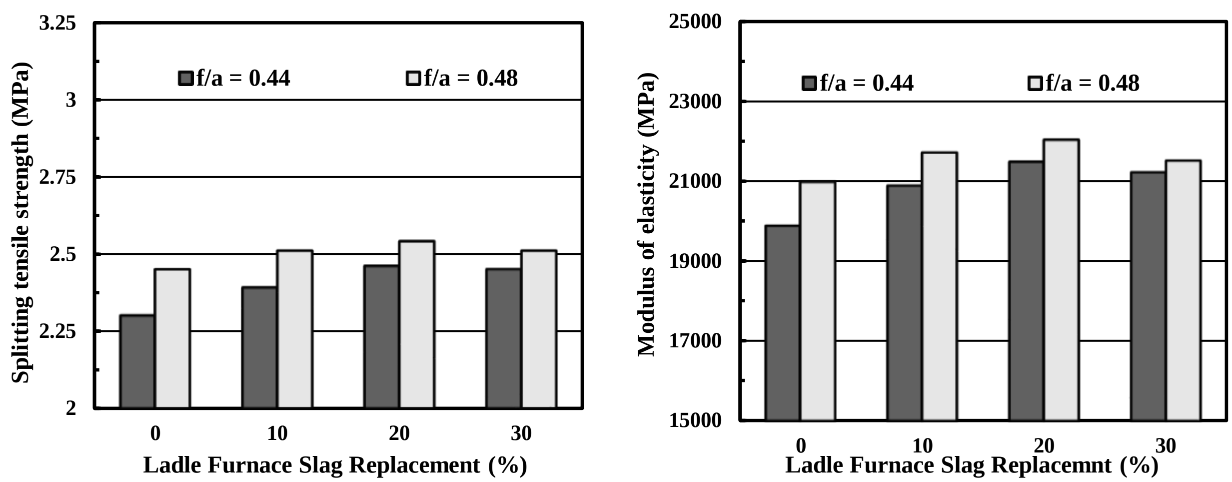


Fig. 8. 28-day tensile strength and modulus of elasticity of concretes made with LFS.

CONCLUSIONS

Based on the results of this experimental investigation on utilization of BFA and LFS as fine aggregates in concrete, the following conclusions are drawn:

1. Workability of concrete decreases with increasing replacement of natural river sand by BFA irrespective of the source,
2. Workability of concrete increases with increasing replacement of river sand by LFS up to 20%, and then the workability starts to reduce with further replacement of river sand by LFS.

3. Compressive strength, splitting tensile strength and modulus of elasticity of concrete increase with increasing replacement of river sand by BFA up to 30%, beyond that, the hardened properties of concrete start to reduce.
4. compressive strength, splitting tensile strength and modulus of elasticity of concrete increase with increasing replacement of river sand by LFS up to 20%, and then start to reduce.

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