Effect of fly ash and bottom ash on the ratio of splitting tensile strength to compressive strength of concrete

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Abstract. The construction industry has suffers from extra ordinary utilization of cement and sand in all the part of globe. For overcome the future scarcity issue partial replacement to cement with option of fly ash material and fine aggregate or sand with bottom ash prove better solution. For this study, effect of different water cement ratio mainly 0.5, 0.55, 0.6 evaluated on binder content 300kg/m³ of concrete. f/c (fly ash/cement) ratio also taken into account with wide range as 0, 0.11, 0.25, 0.43, 0.67 and 1.0. The mechanical strength of concrete specimens evaluated. The traditional practice generally neglected the issue of splitting to compressive ratio(f/tc). In this experimental investigation, the value of f/tc ratio found between ranges 6.76 to 11. This range are principally important for fly ash + bottom ash involvement in concrete for determining mechanical strength which has interlink to each other.

1. Introduction

The sustainability aspect in construction practices has been helps to establishment and ruling of a healthy environmental ecosystem [1]. Today’s need has noted only when they do not negotiate the future material demand [2]. Concrete has become most consumable substance due to their structural behaviour [3], but its negative impact faced by economy [4]. Cement is main focal source in concrete industry and ultimately of greenhouse gas emission [5]. The supplementary materials to cement is well known by SCM’s and it acts a good source for minimizing cement share in concrete. The fly ash as a SCM produced better results [6]. Concrete structure is mainly a combination of cement, sand and stone particles. The cement or cementitious paste, comprised of materials fly ash, silica fume, metakaolin. The slurry, which adheres the stone particles into a concrete mass; mixtures strengthens due to their chemical activity of water called hydration. In concrete structure designing, the uni-axial compressive strength parameter having valued, which is independent by a number of parameters.

The strength characteristic of the concrete is dependable on nature of cementitious material, mortar, stone used and their interface scenario. For the corresponding formation of mortar, the diverse coarse aggregate with respect to shape, texture has been outcome into varied concrete strengths. The utilization of bottom ash and fly ash substitutes sand and cement respectively for concrete constituents. Bottom ash (BA) is compound of silica-alumina-iron with minor range of calcium-magnesium-sulfate. This
compound composition is varied over a wide range due to coal nature of thermal power station [7]. The non-combustible fly ash and bottom ash obtained as thrown ash product of coal. The Electrostatic Precipitators collected ash known as fly ash. Fly ash particles found generally finer than 01 µm. The existing researcher study motivate that BA usable material as sand. It means suitable and usable material for replaceable constituent in concrete. The BA characteristics determined by considering the mechanical characteristics. Aggregates is known as a main skeleton of concrete body and at least (¾) th of the volume has possesses by aggregates. Aggregate is habitually form bond in the cement paste but actually aggregate is not sluggish because physiochemical characteristics has been belongings on the quality of concrete [08]. Some clinkers collected on the boiler surface of furnace and these clinker processed by grinding operation. Final grinded ash collected at lower part of boiler is recognized as bottom ash. this ash has materially grayish, coarser and granular. BA volume generally (1/4)th of the total generated ash, while fly ash (FA) has 75% [09].

In an Asian region the coal based electric power station are the only source of about 60% to 75% power generations. Annually 300 to 350 million tons of coal is utilized. Indian coals have maximum inorganic enclosures nearly 46%. Only 50 million-tons ash has used for cement, and only 10% in concrete and bricks. The most part of available fly ash is still used as a land filling material. Annual volume of TPS bottom ash has been bombard up to 50 million tones. Now a days, a minor use of BA is in practice. The unutilized fly ash and Bottom ash pollutes thousand acres of land and it has cause disturbance in the human-environmental sustainability. In most of the places, dangerous particles of BA cover by wind flow and it pollute the water as well as cultivable land. This migration of power plant ash is easily polluted environment and its proper placement in any suitable place is become important role in society and the strength parameter is considered as a utilization factor of concrete. Bottom ash and Natural River sand has particle size distribution similar to each other. Due to such profitable character, it to be used as sand particles in the concrete constituents.

Now a day’s the replacement possibilities in concrete materials has been increases. Author [10] verified the compressive strength for bottom ash nearly half and full proportions and was found to be about 40% lower strength. The strength of concrete are thoroughly related to proportioning and properties of its inert materials. The researcher [11] investigated that presence of BA as sand in concrete. The reduction seen in strength of concrete because of porous nature of BA and higher water consumption. The strength can been controlled by controlling the water demand with the help of super plasticizers. Researchers [12, 13] experienced the same observation for modulus of elasticity (E) too. It decreased with the increase in bottom ash volume. For 100% sand replacement, the range of (E) found 15% to 16% lower. The split tensile strength (ft) of BA concrete has been era of new concrete. Also detected that (fst) of specimens 20% BA for sand replacement was found more than the control concrete (CC) specimens. The (ft) observations seen decremented effect with increase bottom ash by 20%, whereas researcher [13] is witnessed that no variation in the (fst) up to 10% fine aggregate replacement.

Gebler and Klieger, 1986 [14] measured the effect of ASTM fly ashes from dissimilar sources on the compressive strength and was found improvement of concretes for different modes of curing. The long span impact of the TPS fly ash classes in the concrete not foremost. The FA is used in higher range in the pozzolanic cement as an additive and partially in concrete. Fly ash mortars performs slower strength upto 28days due to the slow rate of pozzolanic reaction [15, 16]. Un and Baradan, 2011 [17] assessed the (fc) and flexural strengths (fr) of mortars containing fly ash and have found the results superior at higher curing temperatures. The count of FA has been frequently observed to improve pores of long life concrete [18, 19]. Finer fly ash particles has beneficial in workability because all spherical particles create grip, liquefied the paste [20], this term is known as ball bearing effect [21]. The Compressive strength (fc) subjected with the water-binder ratio and It rises with reducing water-binder ratio [22]. The split tensile strength has related to several properties such as (fc), w/b ratio and age of curing but many researchers practiced for finding the (ft) directly from (fc). The harden properties of concrete used for structural design are Compressive and tensile strengths. The (fst) is significant for plain concrete. The split tensile strength has been regularly consider for designing dam under earthquake excitations, pavement slabs and airfield runway as bending Strength subjected to tensile effects.
Many researchers have suggested formulae for finding \((f_t)\), the popular of which recommended by ACI. All existing relationships based on compressive strength of concrete. The reliability is defined by integral absolute error \((\text{IAE}, \%)\) [23]. The \((f_t)\) results of concrete has been found inferior than the \((f_c)\), profoundly due to generation of tensile loadings cracks. The \((f_t)\) analysis is lacking because cracks are inclines to be of tensile behaviour. Concrete reflected a brittle material and tends to propagates flaw, micro cracks which created the tensile strength. This study aimed to examine hardened characteristics carrying out using fly ash(FA) and Bottom ash(BA) partial replacement of cement and sand respectively. It is offerings a relationship between \((f_t)\) to \((f_c)\). It tested for early age concrete to regular concrete upto 180days concrete curing.

2. Materials and Methods
For the experimental purpose the Ordinary Portland Portland Cement was used as conforming to BIS 12269-2004 [24]. The Tapi river sand conforming IS 383-1970 [Reaffirmed-2002][25], siliceous pulverized fly ash and bottom ash conforming with IS 3812-Part 2 (2003)[26], and potable quality tap water as per IS 456: 2000 [27] were used for all stages of investigation. The fly ash of F Class \((\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 = 92.73)\) used. The specific gravity of fly ash found 2.15 and cement was 3.15. The bottom ash observed the coarser than the fly ash and cement. The sand were tested for fineness modulus and specific gravity, which obtained 2.55, 2.75 respectively. The coarse aggregates of 20 mm size used for experimentation. The strength of concretes be subject to on an elements and related parameters. The aim of this study focused to evaluate the effect of fly ash. As an outcome of mix variables like advantage of ingredients, mix proportions and curing condition had kept constant for experimentation. At binder content, the variables of key interest are \(w/(c+f)\) ratio and fly ash \((FA)\) replacement. For this purpose, different concrete mixes were done at binder of 300kg/m\(^3\) and water/binder-\(w/b\) ratios \((w/(c + f))\) of 0.5, 0.55 and 0.6. The flyash/cement \((f/c)\) ratio 0, 0.11, 0.25, 0.43, 0.67 and 1.0 were used in the experimental work. The bottom ash in concrete mixes as sand replacement with 15% and 30% kept stable for all specimen mixes and strength assessment executed according to one direction compressive strength. A set of 3 cubes performance were recorded for every decided mix proportioning and the average values considered for evaluations.

3. Results and Discussion
The compressive strength test done as per guidelines discussed in IS 14858:2000 [27] and IS 516:1959 (Reaffirmed 2004) [29]. The used compression-testing machine (CTM) for experimentation and cubes of size 150 mm used for Compressive testing. Fly ash to cement variation i.e. \(f/c\) ratio 0, 0.11, 0.25, 0.43, 0.67, and 1.0 taken into experimentation. Its effects on Compressive strength noted for various curing time at \(w/(c+f)\) ratio 0.5, 0.55 and 0.6. The cylindrical mould of 150mm diameter and 300mm length used for splitting test and samples of specimens. figure 1 shows the pattern of failure during splitting tensile test.
The failure-pattern during splitting tensile test

The fine aggregate combinations of Natural sand to bottom ash considered as (85% : 15%) and (70% : 30%) were used in all specimens. The tabulated results represented in Table 1 to 3 and The splitting strength for w/(c+f) ratio 0.5, 0.55, 0.6 with respect to Control concrete mixes: 15% and 30% bottom ash added for sand replacement and (f/c ratio 0, 0.11, 0.25, 0.43, 0.67, and 1.0) are mentioned in Table 4. Table 5 values indicates the ratio of Split tensile strength (cylinder specimen) to compressive strength (cube specimens) %.

### 3.1 Results of compressive strength (fc)

Notation Used in Table 1,2,3:

- B1=Binder content for 300 kg/m3,
- W1=w/c ratio (0.5),
- W2=w/c ratio (0.55), W3 represents w/c ratio (0.6),
- S15=Bottom ash sand content 15%, Natural sand=85%,
- S30=Bottom ash sand content 30%, Natural sand=70%.

| (f/c) ratio | Mixes Designation | Compressive Strength (N/mm2) |
|------------|------------------|-------------------------------|
|            | 3days | 7days | 28days | 56days | 90 days | 180days |
| 0          | B1W1F0 | 25.61  | 35.53  | 40.23  | 45.33   | 49.97   | 51.01   |
| 0.11       | B1W1F10 | 23.21  | 32.33  | 38.55  | 43.96   | 54.99   | 55.02   |
| 0.25       | B1W1F20 | 18.21  | 25.43  | 36.79  | 38.88   | 41.03   | 41.36   |
| 0.43       | B1W1F30 | 16.35  | 20.77  | 34.31  | 39.56   | 44.81   | 44.98   |
| 0.67       | B1W1F40 | 13.22  | 15.99  | 30.01  | 35.45   | 40.82   | 40.91   |
| 1.0        | B1W1F50 | 6.01   | 8.03   | 20.03  | 25.58   | 31.13   | 31.33   |
| 0          | B1W1-S15F0 | 26.52  | 36.03  | 41.12  | 46.18   | 50.09   | 52.07   |
| (f/c) ratio | Mixes Designation | Compressive Strength (N/mm²) |
|------------|------------------|-----------------------------|
|            |                  | 3days | 7days | 28days | 56days | 90 days | 180days |
| 0          | B1W2F0           | 24.99 | 35.03 | 40.14  | 43.07  | 46      | 46.02   |
| 0.11       | B1W2F10          | 19.36 | 25.97 | 33.54  | 37.27  | 41      | 43.25   |
| 0.25       | B1W2F20          | 16.74 | 21.55 | 28.86  | 34.44  | 40.02   | 42.21   |
| 0.43       | B1W2F30          | 12.57 | 18.33 | 25.26  | 26.69  | 28.13   | 29.98   |
| 0.67       | B1W2F40          | 9.05  | 14.68 | 21.78  | 29.67  | 37.56   | 39.14   |
| 1.0        | B1W2F50          | 6.02  | 8.33  | 14.23  | 19.44  | 24.66   | 25.99   |
| 0          | B1W2-S15F0       | 25.12 | 36.35 | 41.36  | 44.06  | 46.11   | 46.99   |
| 0.11       | B1W2-S15F10      | 20.12 | 26.13 | 33.13  | 38.16  | 42.13   | 44.19   |
| 0.25       | B1W2-S15F20      | 16.48 | 21.47 | 28.03  | 34.05  | 39.18   | 40.08   |
| 0.43       | B1W2-S15F30      | 13.14 | 19.14 | 26.14  | 26.39  | 28.13   | 28.77   |
| 0.67       | B1W2-S15F40      | 10.02 | 12.03 | 20.12  | 28.16  | 36.18   | 38.18   |
| 1.0        | B1W2-S15F50      | 7.01  | 8.5   | 13.03  | 20.68  | 25.13   | 27.36   |
| 0          | B1W2-S30F0       | 25.03 | 35.69 | 41.15  | 44.15  | 46.87   | 47.02   |
| 0.11       | B1W2-S30F10      | 19.19 | 25.39 | 34.46  | 39.28  | 43.44   | 45.16   |
| 0.25       | B1W2-S30F20      | 17.02 | 21.15 | 27.96  | 35.15  | 38.17   | 39.14   |
| 0.43       | B1W2-S30F30      | 13.36 | 19.87 | 27.01  | 28.33  | 30.26   | 30.15   |
| 0.67       | B1W2-S30F40      | 9.07  | 11.03 | 18.36  | 26.33  | 29.12   | 30.01   |
| 1.0        | B1W2-S30F50      | 6.88  | 8.39  | 12.99  | 22.68  | 26.13   | 28.12   |

Table 2. Fly ash replacement (f/c ratio 0, 0.11, 0.25, 0.43, 0.67, 1.0) effects on compressive strength for various curing periods at w/(c+f) ratio 0.55
Table 3. Fly ash replacement (f/c ratio 0, 0.11, 0.25, 0.43, 0.67, 1.0) effects on compressive strength for various curing periods at w/(c+f) ratio 0.6

| (f/c) ratio | Mixes Designation | Compressive Strength (N/mm²) |
|-------------|-------------------|-------------------------------|
|             |                   | 3days | 7days | 28days | 56days | 90 days | 180days |
| 0           | B1W3F0            | 16.74 | 27.28 | 35.21  | 38.16  | 41.12   | 42.45   |
| 0.11        | B1W3F10           | 13.23 | 21.23 | 29.76  | 31.04  | 32.33   | 33.02   |
| 0.25        | B1W3F20           | 9.98  | 18.78 | 28.46  | 30.85  | 33.24   | 34.25   |
| 0.43        | B1W3F30           | 7.83  | 14.83 | 22.79  | 26.51  | 30.22   | 31.97   |
| 0.67        | B1W3F40           | 7.63  | 10.53 | 18.19  | 21.94  | 25.69   | 27.46   |
| 1.0         | B1W3F50           | 5.01  | 6.5   | 14.78  | 19.17  | 23.56   | 25.48   |
| 0           | B1W3-S15F0        | 16.39 | 27.23 | 35.01  | 37.16  | 40.87   | 41.88   |
| 0.11        | B1W3-S15F10       | 13.39 | 20.29 | 29.18  | 32.38  | 34.11   | 34.25   |
| 0.25        | B1W3-S15F20       | 9.03  | 18.17 | 27.29  | 30.44  | 34.11   | 34.25   |
| 0.43        | B1W3-S15F30       | 7.99  | 15.13 | 20.22  | 25.69  | 31.33   | 33.12   |
| 0.67        | B1W3-S15F40       | 7.66  | 10.89 | 18.39  | 22.16  | 26.13   | 28.18   |
| 1.0         | B1W3-S15F50       | 6.18  | 7.88  | 14.33  | 20.12  | 24.13   | 25.09   |
| 0           | B1W3-S30F0        | 16.16 | 27.03 | 34.87  | 37.01  | 40.19   | 41.47   |
| 0.11        | B1W3-S30F10       | 13.93 | 20.29 | 29.18  | 32.38  | 34.11   | 34.25   |
| 0.25        | B1W3-S30F20       | 9.03  | 18.17 | 27.29  | 30.44  | 34.11   | 34.25   |
| 0.43        | B1W3-S30F30       | 7.99  | 15.13 | 20.22  | 25.69  | 31.33   | 33.12   |
| 0.67        | B1W3-S30F40       | 7.66  | 10.89 | 18.39  | 22.16  | 26.13   | 28.18   |
| 1.0         | B1W3-S30F50       | 6.07  | 7.22  | 13.66  | 19.18  | 23.87   | 25.13   |

3.2 Results of splitting tensile strength (ft)

Table 4. F/c ratio effects on splitting tensile strength for various curing periods at w/(c+f) ratio 0.5, 0.55 and 0.6

| (f/c) ratio | Mixes Designation | Splitting tensile Strength (N/mm²) |
|-------------|-------------------|----------------------------------|
|             |                   | w/ (c+f) ratio W1= 0.5 | w/ (c+f) ratio W2= 0.55 | w/ (c+f) ratio W3= 0.6 |
|             |                   | 3days | 28day | 90days | 180days | 3days | 28day | 90days | 180days | 3days | 28day | 90days | 180days |
| 0           | F0                | 1.81  | 3.04  | 3.27   | 3.40    | 1.68  | 3.00  | 3.20   | 3.25    | 1.56  | 2.62  | 2.82   | 2.94    |
| 0.11        | F10               | 1.53  | 2.75  | 3.08   | 3.30    | 1.64  | 2.86  | 3.04   | 3.04    | 1.41  | 2.49  | 2.73   | 2.86    |
| 0.25        | F20               | 1.41  | 2.62  | 2.97   | 3.19    | 1.59  | 2.65  | 2.83   | 2.95    | 1.31  | 2.38  | 2.65   | 2.78    |
| 0.43        | F30               | 1.36  | 2.49  | 2.81   | 3.02    | 1.53  | 2.46  | 2.65   | 2.69    | 1.25  | 2.26  | 2.49   | 2.60    |
| 0.67        | F40               | 1.28  | 2.41  | 2.68   | 2.77    | 1.46  | 2.36  | 2.52   | 2.69    | 1.16  | 2.12  | 2.39   | 2.57    |
For water-to-binder ratio 0.5, the relation between $ft$ and $fc$ as mention below:

| Days    | $ft$ (7 days) | $ft$ (28 days) | $ft$ (90 days) | $ft$ (180 days) |
|---------|--------------|----------------|---------------|-----------------|
| 0.5     | 7.56         | 8.27           | 6.76          | 7.01            |

For water-to-binder ratio 0.55, the relation between $ft$ and $fc$ as mention below:

| Days    | $ft$ (7 days) | $ft$ (28 days) | $ft$ (90 days) | $ft$ (180 days) |
|---------|--------------|----------------|---------------|-----------------|
| 0.55    | 9.06         | 11.0           | 8.43          | 8.42            |

For water-to-binder ratio 0.6, the relation between $ft$ and $fc$ as mention below:

| Days    | $ft$ (7 days) | $ft$ (28 days) | $ft$ (90 days) | $ft$ (180 days) |
|---------|--------------|----------------|---------------|-----------------|
| 0.6     | 8.73         | 9.56           | 8.29          | 8.34            |

The details of equation (1) to (12) are provided in table 5 as below
Table 5. The ratio of split tensile strength (cylinder specimen) to compressive strength (cube specimens) %

| (f/c) ratio | Mixes Designation | Splitting tensile Strength (N/mm²) |
|------------|-------------------|-----------------------------------|
|            | w/ (c+f) ratio W1= 0.5 | w/ (c+f) ratio W2= 0.55 | w/ (c+f) ratio W3= 0.6 |
| 3days 28day 90days 180days | 3days 28day 90days 180days | 3days 28day 90days 180days |
| 0.00 F0   | 5.09 7.54 6.54 6.66 | 4.79 7.46 6.95 6.84 | 5.72 7.43 6.86 6.92 |
| 0.11 F10  | 4.73 7.13 5.60 6.00 | 6.31 8.51 7.41 7.03 | 6.64 8.37 8.45 8.66 |
| 0.25 F20  | 5.54 7.11 7.23 7.71 | 7.39 9.18 7.06 6.99 | 6.96 8.36 7.96 8.11 |
| 0.43 F30  | 6.55 7.26 6.27 6.71 | 8.33 9.74 9.42 9.64 | 8.46 9.89 8.23 8.13 |
| 0.67 F40  | 8.01 8.03 6.57 6.77 | 9.96 10.4 6.70 6.87 | 10.9 11.5 9.32 9.36 |
| 1.00 F50  | 12.2 8.89 7.29 7.94 | 12.1 12.1 8.35 8.96 | 15.6 13.4 9.54 9.45 |
| 0.00 S15F0| 5.08 7.56 6.65 6.51 | 4.70 7.42 7.00 7.00 | 5.72 7.43 6.86 6.92 |
| 0.11 S15F10| 5.61 7.84 6.16 6.14 | 6.62 9.33 7.67 7.49 | 5.95 7.57 6.95 7.09 |
| 0.25 S15F20| 6.98 8.74 8.13 8.06 | 8.15 11.1 8.37 8.43 | 8.13 9.15 8.60 8.88 |
| 0.43 S15F30| 8.52 8.57 6.98 7.57 | 8.88 11.5 11.2 11.1 | 9.41 10.0 8.65 9.08 |
| 0.67 S15F40| 10.54 9.22 7.37 7.42 | 13.3 14.3 8.32 8.15 | 10.4 12.9 8.97 8.88 |
| 1.00 S15F50| 11.66 11.09 8.61 8.94 | 17.0 21.1 11.3 11.0 | 13.4 13.1 10.0 9.83 |
| 0.00 S30F0 | 4.87 7.29 5.97 6.28 | 4.68 7.22 6.72 6.85 | 5.72 7.43 6.86 6.92 |
| 0.11 S30F10| 5.79 8.06 5.60 6.00 | 6.66 8.71 7.27 7.17 | 5.73 7.43 6.99 7.02 |
| 0.25 S30F20| 6.47 8.73 6.14 6.34 | 7.90 10.5 8.20 8.28 | 8.19 9.33 8.29 8.45 |
| 0.43 S30F30| 7.76 7.44 5.79 5.81 | 7.70 10.4 9.85 10.2 | 8.25 9.19 8.44 8.55 |
| 0.67 S30F40| 10.35 8.26 6.65 6.93 | 13.2 9.37 9.58 9.63 | 8.87 7.03 8.12 8.31 |
| 1.00 S30F50| 10.28 10.05 8.04 8.34 | 15.2 19.6 10.1 9.74 | 11.9 12.3 10.0 9.56 |
| Average   | 7.56 8.27 6.76 7.01 | 9.06 11.0 8.43 8.42 | 8.73 9.56 8.29 8.34 |

The researcher Minides and Young, 1981 [30] discussed the effect of (fc) and (ft) strength. The relation were found collateral with strength of concrete, size of aggregate, the log-age, and curing condition. It is creditable to best part that existing relationships established only for conventional concrete, now the conventional OPC concrete practices in the form of blended concrete. To fill out the gap of research, the relation checked experimentally for fly ash+ bottom ash incorporated concrete and to validate for the applicability of the existing knowledge. The relation with splitting test has been proposed values in equation [1 to 12] for w/(c+f) ratios 0.5, 0.55 and 0.6.

4. Conclusion
- The ratio of (ft/fc) decreases as the compressive strength increases for fly ash and bottom ash concrete. The reduction in the ft/fc ratio for 30% replacement observed as 11.82% to 24.69% for curing of 180 days. It also reflected as w/(c+f) value lower to higher range.
- The early age strength has been seen slower rate than the controlled concrete, the similar conclusion observed by existing researchers [31].
• The use of 15% bottom ash satisfying good compressive and tensile strength.
• The more effective results obtained from binder to water content “w/(c+f)” 0.5 rather than 0.55-0.6 for all curing ages (7 days to 180 days).
• The value of splitting to compressive strength of thermal ash concrete has been found between 6.76 to 11.0 for binder content 300 kg/m$^3$ having w/(c+f) considering 0.5, 0.55 and 0.6.
• This point were not touch by existing literature consciously, Therefore the study of split to compressive strength (ft/fc) relation in terms of ratios will help in future experimentation of Fly ash and Bottom ash concrete work.

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