

The Effect of Ratio of Aggregate to Cement Paste Volume on Structural Lightweight Concrete Strength, Viscosity, Density and Cost

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Abstract: Considering the fact that Iran is one of the world's most seismically active countries, the use of lightweight concrete in constructions is reasonable which will reduce the seismic effective weight of the structures and therefore they will be less imposed to earthquake forces. So it is important to study about using lightweight concrete in construction in Iran. Considering the importance of the possibility of industrial production of light weight concrete, the cost effectiveness of design plays an important role in the approval or rejections of such plans. In this study the effect of the ratio of cement paste volume to the aggregate volume on the compression strength, density, viscosity and cost effectiveness of nine different mixture plans is studied. The cost effectiveness of the plans is adjusted by a cost factor based on the average price of materials. Due to the fact that the main goal of our examination is to observe the effects of the volume of binding materials in the plans under study, the water-cement ratio and type of cement (Portland 425-1) is kept constant while the total volume of the cement paste is varied and its effects on the factors noted above is studied. The aggregate materials of these designs include artificial aggregate (Lica) which are tested based on three different types of grading: 1-Light Coarse aggregate+s and 2-Light Fine aggregate+sand 3-Mixture of Coarse and Fine aggregate+sand.

Keywords: Aggregate volume, cost effectiveness, compression strength, natural aggregate, volume of adhesive materials

INTRODUCTION

Due to lower strength of concrete parts relative to Steel parts; the concrete parts have bigger dimensions in comparison with Steel parts and thus the parts form considerable section of dead load of the building in concrete constructions (ACI 213R-03, 2003). The lightweight concrete is often applied as a proper replacement for common concrete as well as for the purpose of weight reduction of structure; even though it's ultimate compression strength is lower in comparison with common concrete. Although the production cost of structural lightweight concrete is higher in comparison with common concrete, but cost increase resulting from exercising special preparation in make of lightweight concrete would be compensated in lieu of each cubic meter, with reduction of dead load and increase of concrete resistance against fire and improvement of concrete' insulator properties. In fact, reduction of dead load causes reduction in dimensions of footing, columns and beams which these cases create numerous economical advantages (ASTM C330-04, 2004).

There exist various approaches for production of lightweight concrete, among them; three main groups are recognizable. The first approach is lightweight aggregate concrete with integrated structure in which

the common lightweight-grain used in the concrete. This type of concrete could be utilized as structural concrete, non-structural concrete or thermal insulator. The second approach is on basis of mingling high volume of void (vacancy) into the concrete which are called as *Foam Concrete or Gas Concrete*. There are also instances exist which lightweight-grain has added to such mixtures. The third approach is the lightweight concrete are made with elimination of fine-grained from concrete which will cause numerous porosities in the concrete. Usually coarse-grained is used in this type of concrete but the use of lightweight-grain to high extent could reduce the specific weight of concrete and create a better thermal insulating properties. These concretes are known as concrete without fine-grained (ACI 213R-03, 2003).

According to definition of U.S. Concrete Institution, the lightweight concrete is consist of a concrete that its specific weight is tangibly less than specific weight of a concrete which are made of natural or crushed aggregate. The structural lightweight concrete generally have a specific mass between 1400-1900 kg/m³ and minimum defined compression strength for them is equivalent to 17 Newton/mm². For regions prone to having earthquake, the codes limit the minimum compression strength of concrete to 28 Newton/mm² (ASTM C330-04, 2004). Alongside of

Table 1: Using materials properties

| Material | Water absorption % (in 30 min) | SSD density (kg/m ³) |
|---|--------------------------------|----------------------------------|
| Portland cement (Type II) | - | 3150 |
| Joshaghan limestone powder | - | 2650 |
| Sand (Metosak company) | 1.5 | 2560 |
| Fine structural leca (Passes from sieve size 4.75 mm) | 8.3 | 1537 |
| Coarse structural leca (Between sieve size 4.75 and 9.5 mm) | 8.2 | 1230 |

effective factors like high strength and low density which have turned the structural lightweight concrete into one of the most applicable materials in resistant structures against earthquake; another one of restrictive factors in production of this type of concrete is its cost. In this study the economy of the plan has adjusted through indicator namely cost factor based on price of consumer materials in Iran's market.

MATERIALS AND PROPERTIES

Materials Properties have shown in Table 1.

Consumer super plasticizer GLENIUM 110 P; production of the BASF Company-The concrete aggregate materials of mixture plans consist of; artificial aggregate (Leca) with three various grading include:

- Mixture of lightweight fine-grained and lightweight coarse-grained plus sand (L-I)
- Lightweight coarse-grained plus sand (L-II)
- Lightweight fine-grained plus sand (L-III)

LECA consists of small, lightweight, bloated particles of burnt clay. The thousands of small, air-filled cavities give LECA its strength and thermal insulation properties. The base material is plastic clay which is extensively pretreated and then heated and expanded in a rotary kiln. Finally, the product is burned at about 1100 °C to form the finished LECA product.

The properties of most lightweight concretes relative to grading of the materials are very sensitive and it has importance that the grading of the plan to be controlled and kept constant (Family and Hakima, 1989). In Fig. 1 to 3 the grading of all plan (L-I, L-II and L-III) has shown.

The mixture plan is determination of the material composition for formation of concrete with acceptable efficiency (sum of fluidity, concentration and bond), considered strength and desirable endurance (durability is consist of preserving features of concrete during time) in a manner that to be economical and practical as well.

In determination of mixture plan there are features like compression strength (in considered concrete), the specific weight of dry and wet concrete, efficiency and slump, endurance (with respect to conditions of environment), standard grading limits (ASTM C 330)

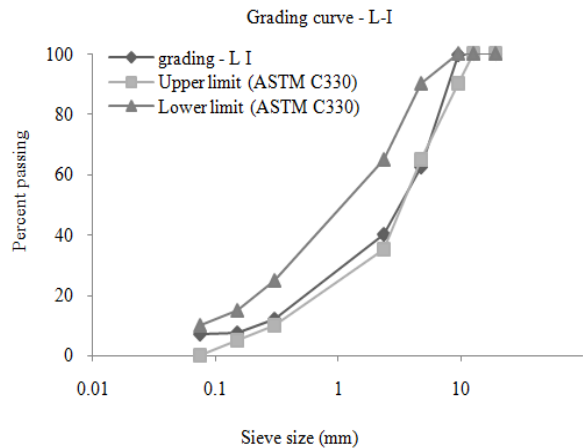


Fig. 1: Grading curve of plan A

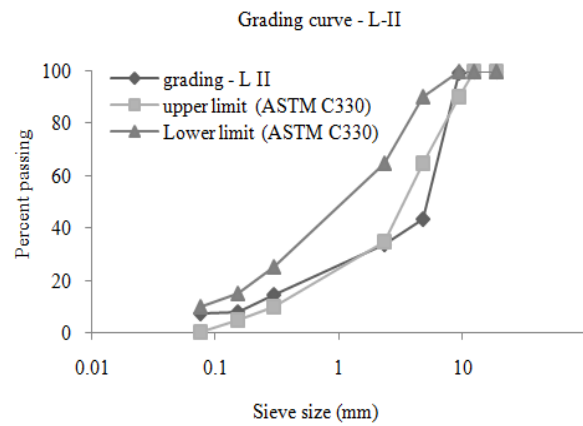


Fig. 2: Grading curve of plan B

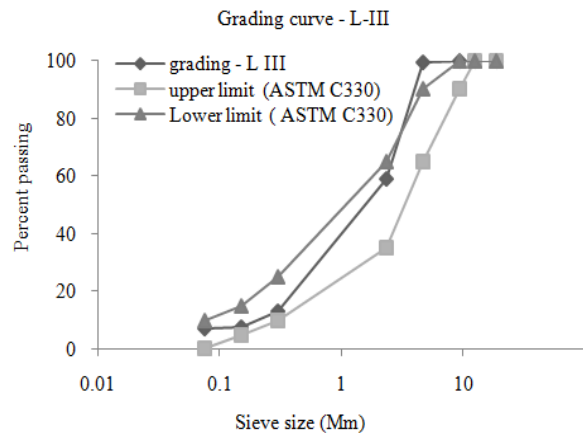


Fig. 3: Grading curve of plan C

and etc., are the determinant factors (Chandra and Berntsson, 2002). In the study the determination approach of mixture ratios is the absolute volume approach in accordance with AC1213R-03 (Ramezani pour and Peydayish, 2012). In this study because the goal of examination is the ratio of

Table 2: The input/output data of excel program

| Input data | V _{agg} /V(Cement+Water) | W/C | Air Vol (%) | Density | Humidity and absorption |
|-------------|-----------------------------------|---------|-------------|---------|-------------------------|
| Output data | V Cement | V Water | V aggregate | - | - |

Table 3: Variation limits of materials

| Materials | Minimum kg/m ³ | | | Maximum kg/m ³ | | |
|-------------|---------------------------|------|-------|---------------------------|------|-------|
| | L-I | L-II | L-III | L-I | L-II | L-III |
| Cement | 384 | | | 512 | | |
| Fine Leca | 326 | - | 652 | 367 | - | 733 |
| Coarse Leca | 297 | 453 | - | 334 | 510 | - |
| Sand | 411 | 642 | 493 | 463 | 722 | 555 |

Table 4: Properties of mixing plans

| Plan code | Agg. grading | V _{agg} /V (cement +water) | Sand (%) | Fine agg. (%) | Coarse agg. (%) | Cement kg/m ³ |
|-----------|--------------|-------------------------------------|----------|---------------|-----------------|--------------------------|
| A1 | L-I | 2.0 | 25 | 35 | 40 | 489 |
| A2 | | 2.5 | | | | 419 |
| A3 | | 3.0 | | | | 367 |
| B1 | L-II | 2.0 | 39 | 0 | 61 | 512 |
| B2 | | 2.5 | | | | 439 |
| B3 | | 3.0 | | | | 384 |
| C1 | L-III | 2.0 | 30 | 70 | 0 | 512 |
| C2 | | 2.5 | | | | 439 |
| C3 | | 2.0 | | | | 384 |

aggregate volume to cement paste volume (volume of cement and water), the primary data are consists of the ratio of aggregate volume to cement paste volume, ratio of water to cement (which have considered constant in all plans) and volume of air; with the help of these data and having the density, water absorption and percentage of humidity exist in the materials, with absolute volume approach could obtain the volume of cement, water and aggregate. The above approach implemented in the Excel program in which the input, output have been explained in Table 2.

With setting the criteria of presented standard grading limits through ASTM C 330 and to specify the volumetric percentages of aggregates, the entire weight of consumer materials is calculated via the compiled program.

The main goal of the examination is the effect of aggregates volume relative to volume of binding materials. For better observation of these effects, the ratio of water to cement and type of cement (Portland Cement Type 2) are considered as constant and the volume of cement paste (volume of cement and water) are interchanged and its effect have studied on compression strength, density, fluidity and economy of the plan.

The variations limits of cement and aggregates weight in volume of one cubic meter have shown in Table 3.

Need to mention that for assurance from proper outcome efficiency, endurance and bond, the amount of cement usually must not be less than 300 kg per cubic meter of concrete. On the other hand, high amount of cement's consumption increases the shrinkage and creep, the heat of hydration during hardening and danger of cracking (Family and Hakima, 1989).

METHODOLOGY

For better comparison of results, each nine built mixture plan has made with a singular approach and same maturing. The mixture trend of materials and order of pouring them into the mixer has performed as follows:

- Whole Leca + $\frac{1}{3}$ sand + $\frac{1}{3}$ water then mix 1 min.
- To add the entire cement, $\frac{1}{3}$ sand and limestone powder and $\frac{1}{3}$ water and $\frac{1}{2}$ of super lubricant then mix 2 min.
- The remainder of sand, water and supper lubricant then mix 8 min.

Table 4 indicates the Properties of mixing plans.

The conditions of maturing has been performed in a way which the samples have kept inside a mold in the humid container for 24 h, then have placed in whitewash for 6 days, 48 h in hothouse and 24 h in laboratory environment. At the time of placing samples into the hothouse, the temperature has increased gradually up to 105°C and after removing from hothouse, through creating proper cover the thermal transfer of samples has prevented.

RESULTS AND DISCUSSION

For each one of three groups of grading, three ratios of aggregate volume to cement paste (Cement+ water) has considered and in total 72 cubical samples with dimensions of 10×10×10 (cm) were built with the form of nine mixing plan.

It is necessary to mention the point that the percentages of aggregates in mixing plans have selected

Table 5: Compression strength and density of mixing plans

| Plan code | Grading | $V_{agg}/V_{(cement+water)}$ | Average Density (kg/m^3) | Average compression strength (MPa) | Slump (Cm) | Cost effectiveness | Average density (kg/m^3) | Average compression strength (MPa) |
|-----------|---------|------------------------------|------------------------------|------------------------------------|------------------|--------------------|------------------------------|------------------------------------|
| A1 | L-I | 2.0 | 1635.75 | 36.53 | 15 | 1.612 | 1624 | 35.3 |
| A2 | | 2.5 | 1604.98 | 36.14 | 10 | 1.621 | | |
| A3 | | 3.0 | 1631.62 | 33.44 | 3.5 | 1.544 | | |
| B1 | L-II | 2.0 | 1651.87 | 34.74 | Very fluent (20) | 1.529 | 1644 | 35.93 |
| B2 | | 2.5 | 1621.61 | 34.61 | 14 | 1.465 | | |
| B3 | | 3.0 | 1658.65 | 38.45 | 7 | 1.416 | | |
| C1 | L-III | 2.0 | 1809.15 | 44.77 | 18 | 1.758 | 1817 | 43.4 |
| C2 | | 2.5 | 1822.00 | 45.39 | 15 | 1.710 | | |
| C3 | | 3.0 | 1819.53 | 40.12 | 4 | 1.674 | | |

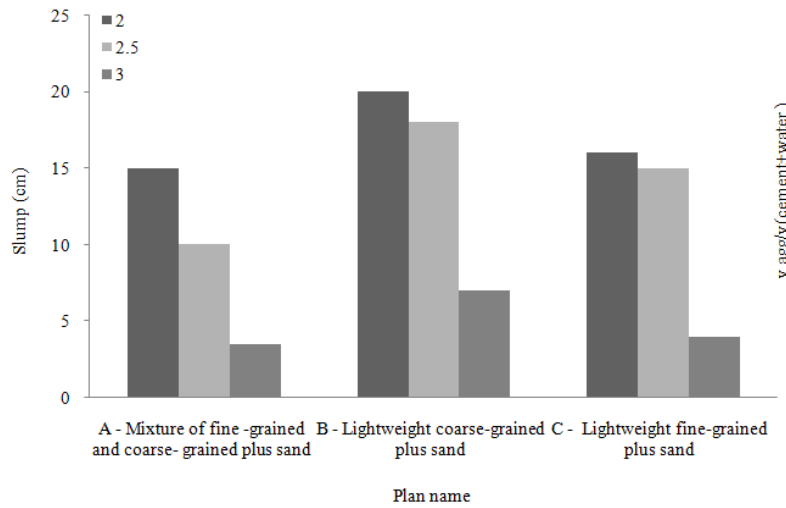


Fig. 4: Comparison of fluidity of three groups of mixing plan A, B and C (Slump)

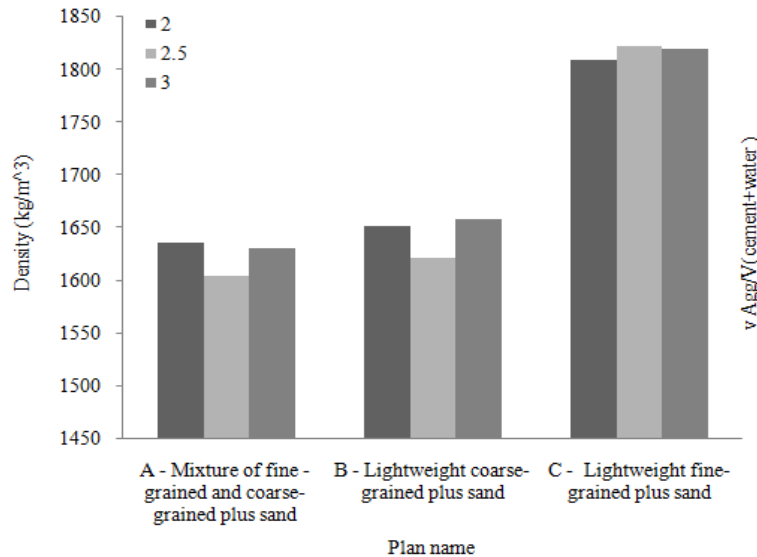


Fig. 5: Comparison of density of three groups of mixing plan A, B and C

in a manner that the obtained grading curve to be as close as possible to the curve limits of aggregates standard (conforms ASTM C330). In the meanwhile, in all plans the ratio of water to cement has considered as constant and equivalent with 0.32. The outcome results

from make of mentioned plans have shown in the Table 5.

In the A and C plans, through increasing ratio of aggregate volume to cement volume from 2 to 2.5 there is no tangible changes has resulted in compression

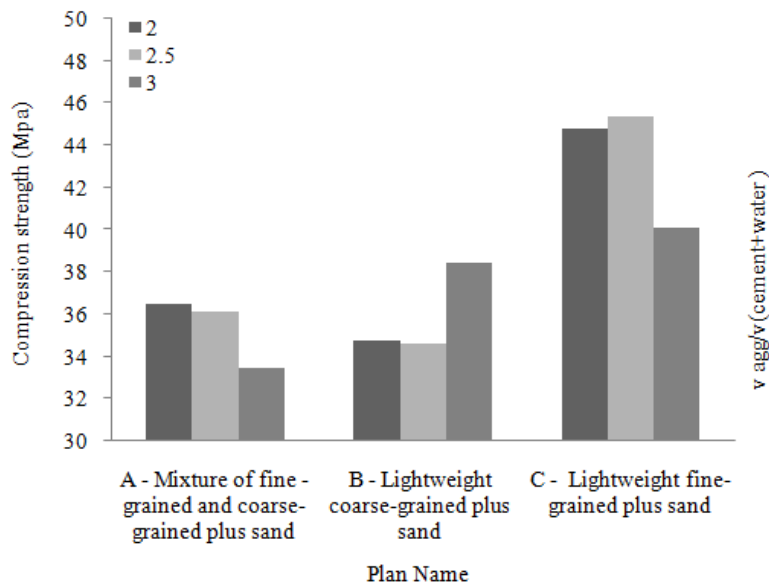


Fig. 6: comparison of compression strength of three groups of mixing plan A, B and C

strength but when this ratio has reached to 3, the reduction in strength is observed which the main reason could be known as reduction in amount of cement and less adhesiveness. In this ratio the amount of cement is 380 kg/m^3 and this indicates that with respect to specific surface of aggregate in Plans A and C the amount is larger than plan B; has not developed required bonding and for the same reason strength reduction has occurred. But in the plan B which fine leca is eliminated; with ratio increase of aggregate volume to cement paste from 2.5 to 3 the increase in strength has occurred. In justification of this result could say that due to less specific surface in this grading, usage from more cement paste has been useless and in addition to cost increase has no effect on strength and in fact, the better state in cement consumption is that the ratio of aggregate volume to cement paste volume to be set equivalent to 3. in Fig. 4, Fluidity of three groups of mixing plan A, B and C have compared.

In Fig. 5 and 6 the variations trend of plans' density and strength has shown with respect to ratio of aggregate volume to cement paste.

One of the limiting factors in lightweight concrete production is its cost effectiveness. In this study the economy of the plan has adjusted based on the price of consumer materials in market. This cost has computed with a recommended relation through code below. The cost of lightweight concrete production with respect to higher price of artificial lightweight-grains relative to gravel and sand is higher. But this perception that because the cost of lightweight-grain concrete production is more than common concrete production therefore is not appropriate to be used in construction is simply wrong perception. The use of lightweight concrete in column has less value since saving is in less weight and in the meanwhile the cost of lightweight

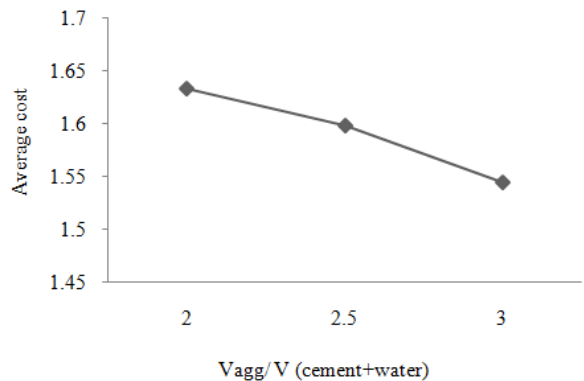


Fig. 7: Comparison of average cost of three mixing plans

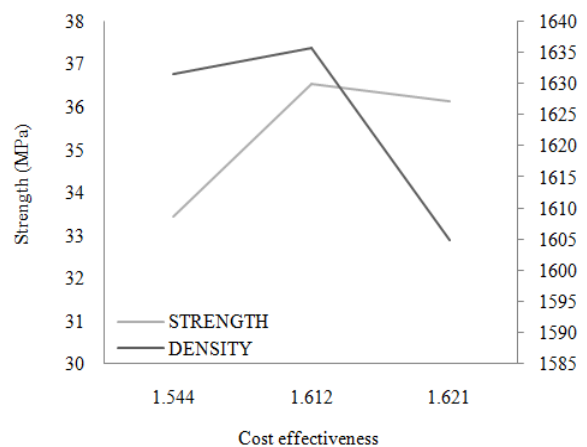


Fig. 8: Variations trend of strength and density in lieu of cost effectiveness for mixing plan A

concrete is more. In an ordinary state the total saving in cost could be 5-7 percent price of concrete skeleton

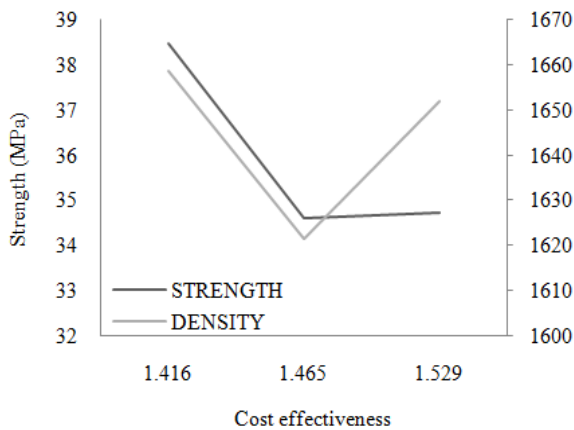


Fig. 9: Variations trend of strength and density in lieu of cost effectiveness for mixing plan B

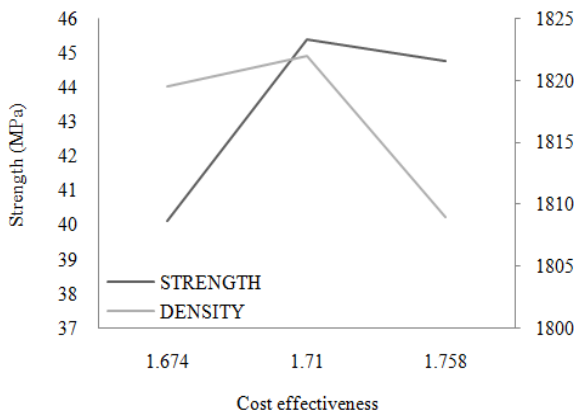


Fig. 10: Variations trend of strength and density in lieu of cost effectiveness for mixing plan C

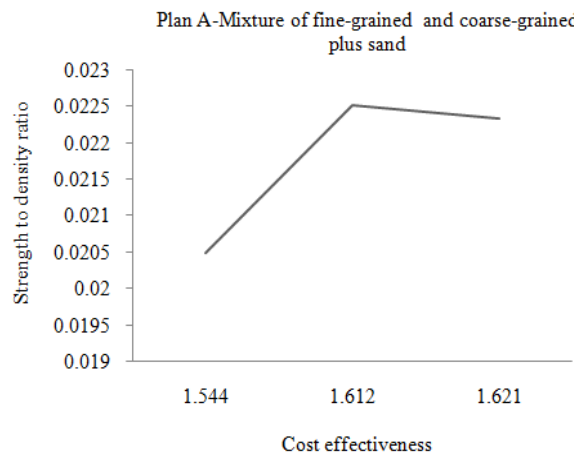


Fig. 11: Variations trend of strength to density ratio in lieu of cost effectiveness for mixing plan A

which usually is less than 0.2% of total cost of building (Family and Hakima, 1989). The following relation is presented for cost calculation of mixing plan:

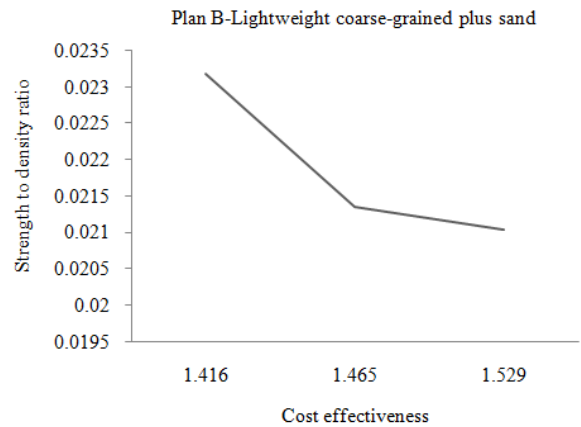


Fig. 12: Variations trend of strength to density ratio in lieu of cost effectiveness for mixing plan B

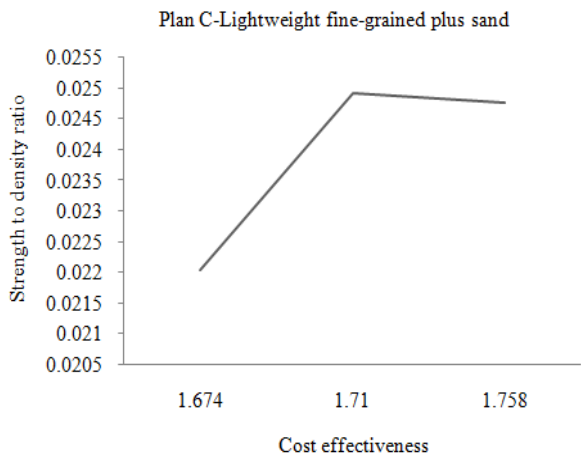


Fig. 13: Variations trend of strength to density ratio in lieu of cost effectiveness for mixing plan C

$$P = \frac{1}{500} \times (0.6 \times \text{cement} + 0.6 \times \text{leca} + 0.075 \times \text{sand} + 0.3 \times \text{filler} + 28.85 \times \text{superplasticizer}) \quad (1)$$

In Eq. (1), the applied coefficient have selected based on the price of a kilogram of materials in the market; for example with respect to the fact that the price of each kilogram of consumer super plasticizer is 28500 Rials then the coefficient of 28.5 have assumed.

In the Fig. 7 the comparison of the average cost in lieu of constant ratio of aggregate volume to cement volume have shown for plans of A, B and C.

In the Fig. 8 to 14 the variations trend of strength and density in A, B and C plans has shown in terms of cost factor:

CONCLUSION

With respect to performed tests their results have shown and compared in tables and figures and the following results are obtained:

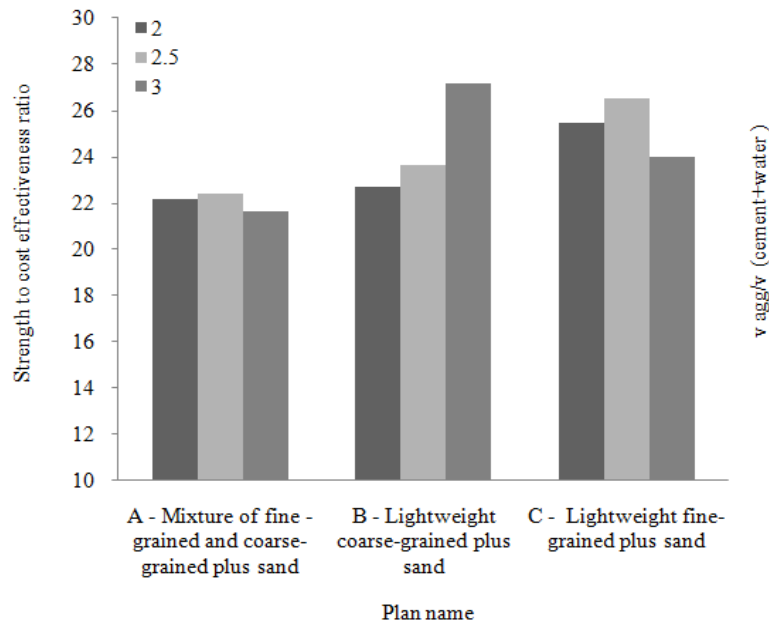


Fig. 14: Ratio of strength to cost effectiveness three groups of mixing plan A, B and C

- For all three groups from mixing plans A, B and C which their aspect of differentiation is in grading, the cost factor and slump (which is an index of fluidity) will be reduced with ratio increase of aggregate volume to cement paste volume.
- With ratio increase of aggregate volume to cement paste volume (volume of cement and water) in a state that the fine leca to be eliminated (Plan B) as a result the specific surface of aggregates becomes less in comparison with two plans A and C. use of cement in the amount of 385 kg/m^3 has shown the highest strength while saving appears with reduction of cement amount and less environmental pollution is developed as well.
- The results of all mixing plans show the point that makes use of ratio 2.5 instead of 2 in aggregate volume to cement paste volume is more economical, since not much considerable difference is observed in compression strength of these two ratios. Instead when the ratio 2, 5 is used the scope of consumer cement becomes less which leads to cost reduction. Of course there develops a little increase in density (30 kg/m^3) which is not much effective.
- The elimination of fine leca and usage from combination of coarse leca and sand have not caused the strength reduction and though in plan B, 60% of volume of aggregate consists of coarse leca, not only separation will not develop but also compression strength have not reduced in comparison with plan A. Meanwhile with elimination of fine leca and increase of coarse leca the possible use from sand which is lot cheaper than leca is arranged so that could increase the strength while reducing cost.
- Although with elimination of coarse leca the strength goes higher, but both density and cost will increase which this case is not desirable for light weight concrete meanwhile with increase of specific surface there is more need to adhesive paste for creating continuity and binding in concrete which will realized with increase of cement. Therefore, the elimination of leca is not desirable.
- In all three plans A, B and C, with increase ratio of aggregate volume to cement paste, the slump which is an index of fluidity will become less. And for constant ratio of aggregate volume to cement paste volume the slump increases with reduction of specific surface.
- In whole, for build of structural lightweight concrete, usage from grading type L-II and the ratio of aggregate volume to cement paste volume of plan B seems to be more desirable.

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