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AN ANALYTICAL STUDY ON EFFECTS OF AGGREGATE SIZES ON THE CONCRETE STRENGTH

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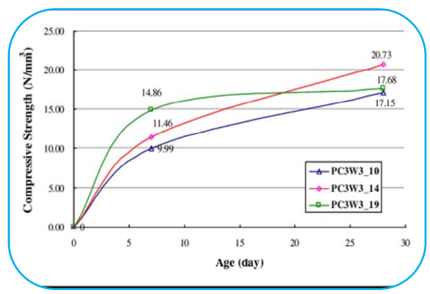
ABSTRACT:

In this ever changing socio-economic, political and cultural scenario, it has been a huge demand to work on the title in determining strength of concrete and the effects of aggregates sizes on the concrete strength. Especially, such as granites stone, black gravel, washed gravel and surface gravel, some factors such as porosity of the aggregate temperature causing loss of water plate form for mixing of concrete mix affect the workability and eventually the strength of concrete. These are the inert or chemically inactive materials which form the bulk of cement concrete. These aggregates are bound together by means of cement. The aggregates are classified into two categories – fine and coarse. It is common knowledge that concrete relies heavily on coarse aggregate. Coarse total normally possesses north of 33% of the volume of cement, and examination demonstrates that adjustments of coarse total can change the strength and break properties of cement. Understanding the effects of aggregate type, size, and content is necessary for making predictions about how concrete will behave under general loading. Only extensive testing and observation can lead to this understanding. Strong evidence suggests that the kind of aggregate used in concrete affects its strength. Concretes made with the same mix proportions and containing four distinct types of coarse aggregate were compared by Ezeldin and Aitcin (1991). They came to the conclusion that, in normal-strength concretes, coarse aggregate strength has little effect on compressive strength, whereas in high-strength concretes, coarse aggregate strength typically results in higher compressive strengths. Other studies have compared the effects of basalt and limestone on high-strength concrete's compressive strength (Giaccio, Rocco, Violini, Zappitelli, and Zerbino, 1992). In cements containing basalt, loadinduced breaks grew principally at the network total connection point, while in cements containing limestone, practically the coarse total particles were all cracked. Darwin, Tholen, Idun, and Zuo (1995, 1996) saw that cements containing basalt coarse total displayed higher bond qualities with building up steel than cements containing limestone.



KEYWORDS: *aggregate, coarse, concrete, porous, compressive strength, fluid mass, etc.*

INTRODUCTION:

Concrete is a compound material made up of cement, coarse aggregate and water – these are the main compound materials of concrete. When the compounds of concrete mixed with each other a *fluid mass* form of concrete is obtained and which can pour into moulds to get a specific desired shape. This fluid mass concrete hardens with respective to time. Actually the cement reacts with other compounds chemically to bind them together to form a hard thing – concrete

Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens (cures) over time. Concrete is the most widely used building material and the second most used substance in the world after water. Its global ton-for-ton consumption is twice that of steel, wood, plastics, and aluminum combined.[citation needed] The ready-mix concrete industry, which is the largest segment of the concrete market, is expected to generate more than $600 billion in revenue by 2025. There are numerous effects on the environment as a result of this widespread use. Most notably, the cement manufacturing process generates large quantities of greenhouse gas emissions, accounting for 8% of global emissions. Other concerns regarding the environment include the widespread use of illegal sand mining, the effects on the environment around it, such as an increase in surface runoff or the urban heat island effect, and the potential health effects of toxic ingredients. To achieve a circular economy, significant research and development are being carried out to reduce emissions or make concrete a source of carbon sequestration, as well as to incorporate more recycled and secondary raw materials. Aggregates are granular materials that include sand, gravel, crushed stone, river stone, and lightweight manufactured aggregates and may occupy up to 75% of the total volume of the concrete. They are expected to be a key material for structures that are resilient to climate disasters as well as a solution to mitigate the pollution of other industries by capturing wastes such as coal fly ash or bauxite tailings and residue. Concrete is also expected to be a key material for structures that are resilient to Since totals are more affordable than concrete glue, they are added to cement to assist with decreasing expenses. The workability of concrete in its plastic state, as well as the durability, strength, density, and thermal properties of hardened concrete, can be significantly influenced by aggregate properties.

The effects of aggregate type, size, and content on the behaviour of normal and high-strength concrete, and the relationships between compressive strength, flexural strength, and fracture energy are discussed. The concrete mixtures incorporate either basalt or crushed limestone, aggregate sizes of 12 mm (0.5 in.) or 19 mm (0.75 in.), and coarse aggregate contents with aggregate volume factors (ACI 211.1-91) of0.75 and 0.67. Water-to-cementitious material ratios range from 0.24 to 0.50. Compressive strengths range from 25 MPa (3,670 psi) to 97 MPa (13,970 psi). Compression test results show that high-strength concrete containing basalt produces slightly higher compressive strengths than high-strength concrete containing limestone, while normal-strength concrete containing basalt yields slightly lower compressive strengths than normal-strength concrete containing limestone. The compressive strength of both normal and high-strength concrete is little affected by aggregate size. High-strength concrete containing basalt and normal-strength concrete containing basalt or limestone yield higher compressive strengths with higher coarse aggregate contents than with lower coarse aggregate contents. The compressive strength of high-strength concrete containing limestone is not affected by aggregate content. Flexure test results show that high-strength concrete containing basalt yields higher flexural strengths than concrete with similar compressive strength containing limestone. The flexural strength of high-strength concrete containing limestone is limited by the strength of the rock and the matrix.

BACKGROUND

This report focuses primarily on the role that coarse aggregate plays in concrete. Even though research on the subject has been going on for a long time, the introduction of high-strength concretes has made it more important to understand how coarse aggregate affects concrete behavior. This is because coarse aggregate plays a smaller but larger role in concrete behavior as strength increases. Debonding of the cement paste from the aggregate particles occurs almost exclusively during compression failure in normal-strength concrete at what will be referred to as the matrix-aggregate interface for the purposes of this report. In contrast, in high-strength concrete, both the interface and the aggregate particles fail, clearly increasing strength overall. The normally stiffer and stronger coarse aggregate and the surrounding mortar are more compatible with one another in terms of stiffness and strength as the cement paste component of concrete becomes stronger. Since the matrix-aggregate bond is stronger than in lower-strength concretes, microcracks tend to spread through aggregate particles because elastic properties mismatches reduce stresses. As a result, high-strength concrete relies heavily on aggregate strength. This report talks about work that aims to learn more about how aggregates work in concrete. Normal and high-strength concretes' aggregate content, size, and type are the variables to be considered. To gain a deeper comprehension of the effects that aggregates have on concrete, compression, flexural, and fracture tests are utilized.

PREVIOUS WORK

Kaplan (1959) studied the effects of the properties of 13 coarse aggregates on the flexural and compressive strength of high-strength and normal-strength concrete. At all ages, flexural strengths for basalt mixes were higher than limestone mixes with the same mix proportions. The compressive strength for basalt mixes was also higher than limestone mixes; however, the difference in strength was less notable in concretes of higher strength. The flexural strength-to-compressive strength ratios for both basalt and limestone mixes ranged from 9 to 12 percent. Kaplan also observed that concrete with 91-day strengths in excess of 69 MPa (10,000 psi) yielded lower flexural strengths than mortar of the same mix proportions; however, concretes below 69 MPa 4 (1 0,000 psi) yielded similar flexural strengths to mortar of the same mix proportions. Kaplan also observed, contrary to most results, that concrete with compressive strengths greater than 69 MPa (10,000 psi) was generally greater than mortar of the same mix proportions, indicating that at very high strengths, the presence of coarse aggregate contributed to the ultimate compressive strength of concrete.

LITERATURE REVIEW

Aggregate refers to the constituent of a composite material that resists compressive load and provides bulk to the composite material. It is mostly used in construction. Aggregates are inert materials like sand, gravel, crushed stone, slag and recycled aggregates. The aggregate of a composite needs to be much smaller than the finished item and should come in a wide variety of sizes for efficient filling. Aggregates account for between 60 to 75% of the total volume of concrete

Aggregate is a component of composite materials such as concrete and asphalt concrete. Aggregate comprises large chunks of material in a composite, commonly coarse gravel or crushed rocks and fine materials. Aggregate comes in two types:

- Fine aggregate – normally consists of sand, crushed stone or crushed slag screenings; most particles pass through a 3/8-inch sieve.
- Coarse aggregate – consists of gravel (pebbles), fragments of broken stone, slag and other coarse substances; particles range between 3/8 and 1.5 inches in diameter.

Aggregate materials are used in building and construction for mixing with cement, bitumen, lime and gypsum to make concrete or mortar. Aggregate helps to provide volume, stability, resistance to wear or erosion, and many other desired properties to the final products. For example, cement is a brittle material in its pure state, but when used with aggregate, the durability and stability of the concrete significantly increases. The redistribution of aggregates after compaction often leads to strength gradients.

Most aggregates are extracted from mines. Aggregate provides reinforcement and adds strength to the overall composite material. Therefore, it is used as a stable foundation or as road/rail bases with predictable properties and inexpensive extenders to the high-cost cement or asphalt.

Aggregates should be clean, hard and free from absorbed chemicals or coatings of clay and other fine materials when added to cement for a good concrete mix. Without cleaning, aggregate can cause the deterioration of concrete quality. Recycled aggregates are also used as partial replacements of natural aggregates in composite materials.

Fine Aggregate/Sand

Fine Aggregates

Fine aggregates are basically natural sand particles from the land through the mining process, the fine aggregates consist of natural sand or any crushed stone particles that are ¼" or smaller. This product is often referred to as 1/4'" minus as it refers to the size, or grading, of this particular aggregate.

Aggregates less than 4.75 mm in size are called fine aggregates; sand falls under the fine aggregate and crushed stone or metal under the coarse aggregates.

Here we will learn about fine aggregates, types of fine aggregates & much more.The maximum size used is 80 mm and the range of 80 mm to 4.75 mn is known as coarse aggregate and 4.75 to 150 μm is called fine aggregate.

Size 4.75 mm is common for both fine and coarse fractions.

Qualities of fine aggregates:

- Fine aggregate should be clean i.e. it should be free from lumps, organic material, etc.
- It should be strong and durable.
- It should not react with cement after mixing.
- Also, it should have a tough floor.
- It should not absorb greater than 5% of water.

These types of aggregates should not be soft and porous

SIEVE ANALYSIS

This is method of dividing a sample of aggregate into fraction, each consisting of particles of the same size. In practice, each fraction contains particles between specific limits, these being the opening of a standard test sieve (B.S 410 of 1969) series for the purpose of testing and the procedure involve in making te sieve analysis also conform tote B.S standard.Sieve analysis is made bypassing the dried aggregate through a series of test sieves beginning with the ones sufficiently coarse to pass all materials.

METHOD OR PROCEDURE

For the purpose of this analysis, the coarse aggregate was washed and allowed to surface-dry in the open air day. Attempt was made to obtain a representative samples of the aggregates by passing the materials in a set of sieves consisting usually of certain standard sizes.

Materials for concrete

The principal ingredients that make up the concrete mix are: cement, fine aggregate, coarse aggregate, water, chemical admixtures, and mineral admixtures. Concrete used in construction may also contain reinforcing bars, welded wire fabric (wire mesh), and various reinforcing fibers. The quality of the ingredients, their proportions, and the way they are mixed all affect the strength of the concrete.

Cement
Water
Coarse aggregates / fine aggregates
Admixtures

The proportion of the materials should maintain in a correct way, as the materials affect the final concrete product. Mainly the water cement ratio should be considered carefully. When the water cement ratio increases, the strength of the final product will be decreased. Concrete is prepared with the consideration of time and placement area. If good -quality concrete is to be produced, then not only must the constituents of the mix be up to standard, but also the equipment used in mixing, transporting, placing and compacting must be suitable for the task. The general properties of concrete mostly coincide with the properties of rock. Concrete is the main component of construction material as it resists compression, flexible to get multiple shapes and reinforced concrete is resistant to the tensile stress too.

The aggregates may also be classified in the following two categories:
(i) Natural aggregates
(ii) Artificial aggregates.

(i) Natural Aggregates:

The term natural aggregate is used loosely to designate aggregates which need only be removed from their natural deposits as unconsolidated sediments. The aggregates obtained from such deposits are called gravel and sand while those produced from ledge rock, boulders or cobble stones are known as crushed stone.

(ii) Artificial Aggregates:

The blast furnace slag is perhaps the only artificially prepared aggregate which is used in the construction. It is obtained as a by-product in the manufacture of steel. If slag is specially manufactured under controlled conditions, it can certainly prove to be an excellent aggregate of uniform quality.

Following are the commonly used admixtures:

Alum, aluminium sulphate, barium oxide, bitumen, calcium chloride, coal ash, common salt, iron oxide, lime, mineral oils, organic oils, potassium chloride, silicate of soda, tar products, volcanic ashes, zinc chromate, etc.

For instance, when calcium chloride ($CaCl_2$) is added as admixture, it absorbs water from the concrete and water-cement ratio falls down and can even be brought down up to the limit of 0.25. Thus it gives quick setting concrete. However, the use of calcium chloride is not suitable for concrete with reinforcing bars.

It is necessary to know the complete detail of any admixture before its recommendation together with the following factors:
(i) Grading curves of aggregates and their respective properties
(ii) Method of construction,
(iii) Quantity of cement per m^3 of concrete,
(iv) Requirement of slump and retention,
(v) Temperature variation,
(vi) Type and make of cement, and
(vii) Water-cement ratio.

Depending upon their respective activities in the concrete mix, the admixtures can be classified in the following five categories:
(i) Accelerators,
(ii) Air entraining admixtures,
(iii) High range of water reducers or super plasticisers,
(iv) Normal range of water reducers or plasticisers, and
(v) Retarders.

It may be noted that some admixtures may have the combined effect of the above individual activities.

The popularity of various, types of admixtures in concrete is increasing rapidly because of the following advantages available from their use:
(i) Adjusting the final setting times of concrete,

(ii) Higher early and ultimate strengths,
(iii) Higher slump and self-levelling concrete,
(iv) Increasing durability of concrete,
(v) Lesser water-cement ratios,
(vi) Reducing quantity of cement,
(vii) Reduction in the permeability of concrete,
(viii) Time savings in terms of repair and maintenance, etc.

Sea Water for Making Concrete:

It is advisable to use clean water fit for drinking purposes for making cement concrete. However, at places where sea water is available in abundance and potable water is costly, the sea water can be used for making cement concrete.

The problem of using sea water for making cement concrete has to be studied from the following two aspects:

(1) Strength
(2) Corrosion of reinforcement.

(1) Strength:

Table shows the analysis of average sea water. It contains about 3.50 Per cent of dissolved salts. The approximate Percentages of various salts are 78 per cent of sodium chloride, 15 per cent of magnesium chloride and magnesium sulphate and the rest 7 per cent of calcium sulphate, potassium sulphate, etc.

TABLE 8-1
COMPOSITION OF AVERAGE SEA WATER

No.	Constituent		Content in gm per litre
1.	Calcium	(Ca)	0.43
2.	Chloride	(Cl_2)	19.80
3.	Magnesium	(Mg)	1.33
4.	Potassium	(K)	0.40
5.	Sodium	(Na)	11.00
6.	Sulphate	(SO_4)	2.76
			Total 35.72

Now all chlorides tend to accelerate the setting of cement and to improve the strength of concrete in early stages. On the other hand, the sulphates tend to retard the setting of cement and to discourage the strength of concrete in early stages.

It is found that the net effect of these two contradictory actions is the fall in strength of concrete to the tune of about 8 to 20 per cent. Hence the sea water can be used for making cement concrete for structures where such fall in strength is permissible or where it is possible to correct the same by adjusting water-cement ratio, cement content in concrete, etc.

The sea water tends to develop dampness and efflorescence. Hence it can be adopted for concrete structures where finishing characteristics are not important or where persistent dampness of the surface is permissible.

(2) Corrosion of Reinforcement:

It is found that the sea water does not lead to the corrosion of reinforcement, provided the concrete is dense and there is enough cover to the reinforcement.

The minimum cement content for concrete permanently under sea water should be 3 kN per m^3 and the minimum cover over the reinforcement should be 75 mm. However, it is not advisable to take the risk of corrosion of reinforcement for pre-stressed concrete and hence the sea water should not be used for making pre-stressed concrete

AGGREGATE SIZE:

There are generally two types of aggregates for concrete: coarse and fine. The majority of fine aggregates are composed of natural sand or crushed stone, with the majority of the particles passing through a sieve of 3/8 inch (9.5 mm). Coarse aggregates typically have a diameter between 3/8 and 1-1/2 inches (9.5 mm and 37.5 mm). Concrete's coarse aggregate is primarily composed of crushed stone, though smooth river rock is also utilized. An absence of fine totals can bring about over the top dying, challenges while siphoning cement, and difficulties while scooping smooth surfaces. The shape or texture of the aggregate has little effect on the bond strength of fine aggregates because smaller particles provide a large amount of surface area for bonding. The surface properties of fine aggregate can have an effect on how much water is needed to keep concrete workable. Acceptable standards include a minimum aggregate size of less than one-fifth of the narrowest dimension between forms' sides, one-third of the depth of slabs, or three-fourths of the minimum clear spacing between reinforcing bars.

In order to lessen the amount of cement required and the drying shrinkage of the concrete, it is sometimes recommended to employ the largest aggregate size possible. Large, coarse aggregate increases the likelihood of bond failure between the aggregate surface and the cement paste that surrounds it due to the higher stresses at the interface than with smaller aggregate. Moreover, it lessens the all out surface-holding region that is accessible.

The rigidity and deformation properties of the aggregate are also crucial. Due to the extreme differences in properties between aggregate and cement paste, high stresses can result in microcracks that can weaken concrete.

Grading Aggregate

Very much evaluated total is the aftereffect of involving many sizes of total in the blend. The amount of cement paste required to fill the gaps or voids between the individual aggregate pieces is reduced as a result of this. The heat of hydration and shrinkage, both of which can cause concrete to crack, can be reduced by reducing the percentage of cement paste in the mix. It also makes it last longer. The packing density of a mix is the amount of aggregate used. All around evaluated total has preferred pressing thickness over hole reviewed total. Hole evaluated total has no middle of the road estimated pieces, which makes the substantial more challenging to place and builds its expense, and both of these elements can influence the eventual outcome.

Moisture Content

The degree of porosity of different aggregates varies; that is, they are capable of absorbing various amounts of water. Concrete reacts differently to highly porous stone depending on whether it is wet or dry before being mixed in. The concrete may become stiffer and more challenging to work with as a result of the dry stone's increased capacity to absorb water from the mix, which may manifest itself as visible issues in the finished product. When figuring out how much water to add to the mix, water in saturated stone must be taken into account or the water-to-stone ratio could be too high, making the concrete weaker.

There are four moisture levels:

1.Broiler dry (OD) implies that all dampness has been taken out.
2.Air-dry (AD) indicates that internal pores are partially filled and surface moisture has been removed.
3.Saturated surface-dry (SSD) indicates that all internal pores are full and the surface moisture has been removed.

4.When something is wet, the pores are full and a surface film exists.

Heavyweight Aggregates

Heavyweight totals are generally utilized in structures requiring radiation safeguarding and are not of worry to most assessors.

Waste Materials as Aggregate

Several concepts for reusing waste materials have been considered and tried. Concrete problems may be brought to inspectors' attention by materials that have been used in place of aggregate in an inappropriate way.

Some of those waste materials include:

- building rubble;
- industrial waste; and
- mine tailings.

CURING

Curing is a process during which a chemical reaction (such as polymerization) or physical action (such as evaporation) takes place, resulting in a harder, tougher or more stable linkage (such as an adhesive bond) or substance (such as concrete). Some curing processes require maintenance of a certain temperature and/or humidity level, others require a certain pressure.Curing involves any process where heat is used to catalyze or initiate chemical and molecular-level structural changes in a polymeric material such as epoxies, phenolics, polyesters and silicones. These materials are applied in many ways to various products for bonding, protective coating, sealing, insulation and other uses.In polymerization, curing is a term in polymer chemistry and process engineering that refers to the toughening or hardening of a polymer material by cross-linking of polymer chains, brought about by electron beams, heat or chemical additives. When the additives are activated by ultraviolet radiation, the process is called UV cure. In rubber, the curing process is also called vulcanization.

Making and Curing Compression Test Specimen in the Field The test specimens are stored on the site at a place free from vibration, under damp 1 matting, sacks or other similar material for 24 hours + -hour from the time of addition of 2 water to the other ingredients. The temperature of the place of storage should be within the range of 22' C to 32'C. After the period of 24 hours they should be marked for later identification, removed from the moulds and unless required for testing within 24 hours, stored in clean water at a temperature of 24' C to 30' C until they are transported to the testing laboratory. They should be sent to the testing laboratory well packed in damp sand, damp sacks, or other suitable material so as to arrive there in a damp condition not less than 24 hours before the time of test. On arrival at the testing laboratory, the specimens are stored in water at a temperature of 27' C + 2' C until the time of test. Records of the daily maximum and minimum temperature should be kept both during the period the specimens remain on the site and in the laboratory particularly in cold weather regions.

Effect of coarse aggregate sizes in concrete:

- As the sizes of coarse aggregate increases then the compressive strength will also increase with constant water to cement ratio(w:c -0.5 and Mix proportion 1:2:4)
- The workability of concrete gets improved after increasing larger sizes of aggregates in concrete
- The various result indicates that the sizes of coarse aggregate are directly proportional to the slump value of fresh concrete
- Coarse aggregate sizes adversely affect the cement aggregate Bond

Testing of Hardened Concrete

There are several reasons why testing of hardened concrete is important: (1) test can investigate the fundamental physical behaviour of concrete such as elastic properties and strength characteristics; (2) When physical laws are not fully understood testing can simulate expected conditions to evaluate performance; (3) tests to determined physical material constants like the modulus of elasticity; and (4) quality control.

CONCLUSIONS AND RECOMMENDATION

The purpose of this investigation is two-fold: (I) to determine the effects of aggregate type, size, and content on the compressive strength, flexural strength, and fracture energy of normal and high-strength concrete, and (2) to determine the relationships between these three measures of materials performance. The concrete in this study incorporates either crushed basalt or limestone coarse aggregate with sizes of 12 mm (Y, in.) or 19 mm (%in.), and coarse aggregate contents with aggregate volume factors (ACI 211.1-91) of 0.67 or 0.75. Watertocementitious materials ratios range from 0.24 to 0.50. Compressive strengths range from 25 MPa to 97 MPa (3,670 psi to 13,970 psi). Fifteen batches (5 normal-strength concrete and 10 high-strength concrete) of 9 specimens each were tested (except for HL-12h.l where only 6 specimens were tested). The results of 45 compression, 45 flexural, and 42 fracture energy tests are reported. Normal-strength concrete was tested at an age of 5 days and high-strength concrete was tested at ages of 94 to 164 days. Specimens were tested in compression and flexural using a 180,000 kg (400,000 lb) capacity hydraulic testing machine. Fracture energy tests were performed using an MTS closed-loop servo-hydraulic testing system.

Increasing the granular composition of the aggregate increases the efficiency utilization of cement in concretes working in compression. At the same time, there is a reduction in deformation and an increase in Young's modulus and unit weight of the concrete. The tensile strength of the concrete is severely affected by increasing the size of the aggregate.

On increasing the maximum grain size to 120–180 mm, the reduction in tensile strength is 30–50% as compared with concretes with maximum aggregate size 20 mm. There is also a reduction in the elongation limit.On increasing the aggregate size, homogeneity of the concrete deteriorates, and the values Rp and R_{pb} approach each other, even on specimens of the same cross-sectional dimensions.When designing concretes for given strength and deformation properties, the coarseness of the aggregate is one of the most important technological parameters.

FUTURE WORK

Although this study provides insight into the effects of aggregate type, size, and content in normal and high-strength concrete, a number of important questions cannot be answered with the available data. Of particular interest are the effects of aggregate size on the compressive strength, flexural strength, and fracture energy of concrete containing limestone. Tests need to be conducted to determine if differences in aggregate size affect concrete containing limestone as it affects concrete containing basalt. The test results analysed in this study are for concrete compressive strengths ranging from 25 to 30 MPa (3,670 to 4,430 psi) and from 62 to 96 MPa (9.070 to 13,970 psi). To obtain a complete understanding of the effects of aggregate type, size, and content, tests are required for compressive strengths spanning between the strength ranges, and also at later test ages for normal-strength concretes and earlier test ages for high-strength concretes. Another aspect of the current study that needs further examination is the relative influence of (1) a larger maximum aggregate size and (2) a much lower coarse aggregate content for both normal and high-strength concretes. Finally, a microscopic analysis of the concrete matrix and interfacial transition zone is needed to develop a complete understanding of the effects of aggregate on concrete. Only through a full understanding of the response of concrete under general 49 loading can the behaviour of this important construction material be understood.

REFERENCES:

1. *Gagg, Colin R. (1 May 2014). "Cement and concrete as an engineering material: An historic appraisal and case study analysis". Engineering Failure Analysis. **40**: 114–140. doi:10.1016/j.engfailanal.2014.02.004. ISSN 1350-6307.*
2. *Crow, James Mitchell (March 2008). "The concrete conundrum" (PDF). Chemistry World: 62–66. Archived (PDF) from the original on 9 October 2022.*
3. *"Global Ready-mix Concrete (RMC) Market worth over USD US$ 624.82 Bn by 2025: QY Research, Inc". Digital Journal (Press release).*
4. *"The Cement Sustainability Initiative: Our agenda for action" (PDF). World Business Council for Sustainable Development. 1 June 2002. p. 20. Archived from the original on 14 July 2007. Retrieved 12 April 2021.*
5. *Lehne, Johanna; Preston, Felix (2018). Making Concrete Change: Innovation in Low-carbon Cement and Concrete (PDF). London: Chatham House. pp. v. ISBN 978-1784132729. Archived (PDF) from the original on 9 October 2022.*
6. Jump up to:***a b c d*** *Lehne, Johanna; Preston, Felix (13 June 2018). "Making Concrete Change: Innovation in Low-carbon Cement and Concrete".*
7. *Li, Zongjin (2011). Advanced concrete technology. John Wiley & Sons. ISBN 978-0470902431.*
8. *Industrial Resources Council (2008). "Portland Cement Concrete". www.industrialresourcescouncil.org. Retrieved 15 June 2018.*
9. *National Highway Institute. "Portland Cement Concrete Materials" (PDF). Federal Highway Administration. Archived (PDF) from the original on 9 October 2022.*
10. *Allen, Edward; Iano, Joseph (2013). Fundamentals of building construction : materials and methods (Sixth ed.). Hoboken: John Wiley & Sons. p. 314. ISBN 978-1118420867. OCLC 835621943.*
11. *"concretus". Latin Lookup. Archived from the original on 12 May 2013. Retrieved 1 October 2012.*
12. Jump up to:***a b*** *Gromicko, Nick; Shepard, Kenton (2016). "The History of Concrete". International Association of Certified Home Inspectors, Inc. Retrieved 27 December 2018.*
13. *Moore, David (6 October 2014). "Roman Concrete Research". Romanconcrete.com. Archived from the original on 6 October 2014. Retrieved 13 August 2022.*
14. *Heinrich Schliemann; Wilhelm Dörpfeld; Felix Adler (1885). Tiryns: The Prehistoric Palace of the Kings of Tiryns, the Results of the Latest Excavations. New York: Charles Scribner's Sons. pp. 190, 203–204, 215.*