

# CONCRETING METHODS THAT PRODUCE LOW CARBON

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## Abstract

A new types of concretes have been produced recently which is completely dissimilar from the conventional concrete in the method of mixing, handling, pouring, consolidation, behaviours, cost .....etc., Such as two-stage concrete (TSC) and Rock-Filled Concrete (RFC). Two-stage (Pre-placed Aggregate) concrete (TSC) unlike normal concrete (NC), it is made by first placing the coarse aggregate in the formwork and then injecting a grout consisted of sand, cement and water to fill the voids between the aggregate particles. The main benefits of the method are widely appreciated as Low heats of hydration, high compressive strengths and density, economic savings, practically no mass shrinkage, low coefficient of thermal expansion, excellent bond to existing structures. A new type of concrete named rock-filled-concrete (RFC), which was based on the technology of self-compacting concrete (SCC), has already been employed in hydraulic engineering structures. The construction technology of RFC mainly consists of two processes: filling the working space with large scale rock mass and pouring the SCC into the pre-packed rock body. Less cement in the composite, which results in less heat of hydration, makes the temperature control of RFC much easier, and this new construction method leads to fast construction speed, high concrete quality and low cost.

This paper presents two special types of concrete; two-stage concrete and rock filled concrete and presents the advantages and special requirements for each of the two special types of concrete and their uses.

**Keywords:** Two-Stage Concrete, Rock Filled Concrete, Self Compacting Concrete, Mass Concrete Construction

# 1. Introduction

The concrete industry has been widely developing in many ways such as the methods of pouring concrete in order to achieve high quality concrete and low cost. Some of these new concretes have been produced which is completely different from conventional concrete in the method of mixing, pouring with no need for the normal compaction methods which require more labour, tools and higher costs. This paper presents two special types of concrete: Two-Stage Concrete and Rock Filled Concrete. Two-stage (Preplaced aggregate) Concrete is a simple concept; it is made using the same basic constituents as traditional concrete: cement, coarse aggregate, sand and water as well as mineral and chemical admixtures. As the name implies, the coarse aggregate is laid first then the cement grout is poured by pumping tubes which are directed to the bottom of the formwork. The grout fills the voids between the aggregate particles. The Two-Stage Concrete differs from conventionally placed concrete in that it contains a higher percentage of coarse aggregate; consequently, the properties of the coarse aggregate appear to have a greater effect on the properties of the concrete, Abdelgader and Najjar. (2009). The second type is special concrete known as Rock Filled Concrete, RFC, which is a combination of consolidation Self Compacting Concrete (SCC) and large block or rock with the minimum size of 300mm. In general, RFC is produced by filling the working space with large-scale blocks of rock to form a rock-block mass first, and then, by either pumping SCC into the working space or pour it directly on to the surface of rock-block mass. The environmental impact of RFC should be assessed in addition to the engineering and economic advantages mentioned above. More than a half of RFC volume is composed by rock mass with a grain-size larger than 30cm, which could be used in the job site without any other treatment. And it only needs to mix SCC to fill the space between rock blocks, which is the rest minor part of RFC, Warner (2005). The employment of RFC not only reduces the quantity of cement in concrete, but also reduces the scale of aggregate processing plant and the concrete mixing plant, which results in the reduction in environmental load and energy consumption. The advantage and special requirements for each of the two special types of concrete and their uses are presented in this paper.

## 2. Two-stage concrete

Two-Stage concrete (TSC) is considered to be one of the modern techniques in the concreting industry. Two-stage (Pre-placed Aggregate) concrete (TSC) unlike normal concrete (NC), it is made by first placing the coarse aggregate in the formwork and then injecting a grout consisted of sand, cement and water to fill the voids between the aggregate particles as shown in Figure 1. The technology of concrete made in this two-stage method is quite different from the normal traditional concrete, not only in the method of placement but also in that it contains a higher proportion of stone aggregate; consequently, the properties of the coarse aggregate appear to have a greater effect on the properties of the concrete than on the cement mortar.

## 2.1 Properties of coarse aggregate

The choice of stone aggregate is of great importance in respect to the two-stage concrete method; the aggregate that is used in (TSC) should be washed, free of surface dust and other impurities. The void content of the aggregate should be as low as possible and is usually achieved when the coarse aggregate is graded uniformly from the smallest allowable particle size to the largest size, ACI 304R (2005). It is typically 40 mm or larger; if aggregates smaller than 20 mm are used then the injected grout tends to bridge the interstices, thereby impeding grout flow. The mechanics of the two-stage concrete is depended on the mechanical properties of the coarse aggregate, because of the point-to-point contact of the coarse aggregate.

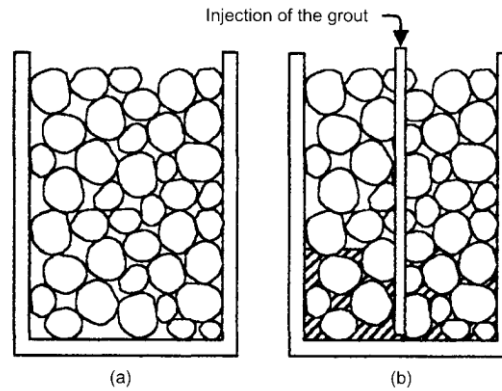


Figure 1: Philosophy of TSC concreting

## 2.2 Properties of grout

The grout that is used in (TSC) normally consists of ordinary Portland cement and well graded sand. The flow of the grout around the aggregate is essential, therefore some admixtures are normally recommended to improve the flow of the grout, improve penetrability, and control the potential for both shrinkage and bleeding.

## 2.3 Propagation of mixture in coarse aggregate

The problem of flow and curve of mixture propagation in coarse aggregate is an important economic question. Mathematically the description of propagation is very difficult. General empirical equation of propagation curve has been derived, Abdelgader (1999), and described in Equation1 as follows:

$$y = \frac{\alpha}{(\beta x^2 + 1) \sqrt{\frac{\gamma}{t} - \frac{1}{\beta} + 1}} \quad (1)$$

Where:  $\alpha$  = thickness of stone layer (m);  $\beta = (a \times b \times f)$ ;  $a$  = parameter dependent of mixture fluidity.;  $b$  = parameter dependent of stone : shape, size, kind of grain, surface, number and relation of fraction;  $f$  = Environment of construction;  $\gamma = (c \times d \times e)$ ;  $c$  = parameter dependent of

efficiency of flushing pipe(m<sup>3</sup>/min.); d=parameter dependent of perforation; e= parameter dependent on the kind of excavation bottom; t = time (min.); x = distance from flushing pipe (m); y = level of mixture mirror in stone (m).

## 2.4 Grouting systems

The injection is achieved by pumping the grout through vertically mounted pipes which almost reach the bottom of the section to be cast. These pipes are rigid, normally 20 mm in diameter and placed at 1.5 m centres, ACI 304R (2005). As the grout is pumped into the form the injection pipes are slowly raised. Injection of grout into small units can be achieved by pumping into the bottom of the form.

## 2.5 Advantages of using TSC

The two-stage concrete completely differs from the normal concrete in the placement and implementation method. Some of the advantages of two-stage concrete are given as following:

### 2.5.1 Economics

The cost of two stage concrete is nearly 40% less than the cost of normal concrete. This is related to the reduction of cement content by some 30% with no need for compaction or vibrating, Abdelgader (1995). In the case of using (TSC) method for underwater concreting, the cost of water-tight forms and dewatering may be eliminated and preparatory work can be done under water.

### 2.5.2 Compressive strength of TSC

The compressive strength ( $f_c'$ ) of two-stage concrete was tested with and without admixture at 28 days. Based on the results, a relation for  $f_c'$  has been assumed, according to the design algorithm presented Abdelgader (1999). For the compressive strength of two-stage concrete ( $f_c'$ ), an empirical equation was calculated using the following formulae:

$$f_c' = A + (B) * w/c + (C) * (w/c)^D + (E) * c/s \quad (\text{MPa}) \quad (2)$$

Where:  $f_c'$  stands for the estimated compressive strength of two-stage concrete,  $w/c$  is the water-to-cement ratio and  $c/s$  is the cement-to-sand ratio. Table 1 presents the values of the regression coefficients.

The experimental results from Equation 2 shows that the effects of different types of admixtures on the compressive strength of two-stage concrete. Compressive strength without admixture was found lower than compressive strength with admixture (super plasticizer). The possible reason for this decrease in strength was due to the low fluidity of the grout. Same behaviour noticed when super plasticizer was used to achieve a grout with high fluidity. The possible reason for

the low strength in the series (super plasticizer) might be associated with the bleeding of water in grout as observed through a transparent cylinder tube.

*Table 1 Regression coefficients of equation (2)*

Type of grout	A	B	C	D	E	R <sup>2</sup>
Without admixture*	-3.67	11.20	3.96	-1.79	3.70	0.883
Superplasticizer	43.90	-32.55	-3.27	-1.68	2.42	0.944
Expanding admixture	-14.31	-39.83	68.45	0.47	2.63	0.891
Combination of superplasticizer and expanding admixture	-25.70	-87.70	126.75	0.52	1.88	0.660

\*Does not include water/cement ratio = 0.38 at all cement sand ratios

### 2.5.3 Tensile strength of TSC

The tensile strength of TSC was investigated at 28 days. The tensile strength is calculated using equation 3 as specified by ASTM C 496 (1990), as follows:

$$f_t = 2P / \pi HD \quad (3)$$

Where:  $f_t$  = tensile strength; P = maximum applied load; and H and D = length and diameter of the specimen, respectively.

The values of tensile strength for grout proportions are estimated by equation 4. No cause was apparent for the relatively high tensile strength. However, it is believed that the amount of coarse aggregate content, method of placement and the greater mechanical interlocking among the particles could be responsible for the high tensile strength. Failure in tensile strength was restricted principally due to the line of split and occurs through the mortar and coarse aggregate.

$$f_t = A + (B) * w/c + (C) * (w/c)^D + (E) * c/s \quad (\text{MP}) \quad (4)$$

Where:  $f_t$  stands for the estimated tensile strength of two-stage concrete, w/c is the water-to-cement ratio and c/s is the cement-to-sand ratio. Table 2 demonstrates the values of the regression coefficients.

### 2.5.4 Compressive and tensile strength of TSC

There is a good correlation between the compressive strength and tensile strength of (TSC). The compressive strength and the tensile strengths of (TSC) were investigated at 28 days for all grout proportions. On the basis of these results a relationship between tensile and compressive strength of TSC has been statistically derived. See Equation 5.

$$f_t = (A) + (B) + f_c + (C) \times (f_c)^D \text{ (MPa)} \quad (5)$$

Where:  $f_t$  is tensile strength and  $f_c$  is compressive strength, A,B,C and D are regression coefficients given in Table 3, Abdelgader and Elgalhud (2008). The measured tensile strength of TSC is in fact higher than that predicted by the ACI equation for conventional concrete. The greater mechanical interlocking among the particles could be responsible for this high tensile strength.

*Table 2 Regression coefficients of equation (4)*

Type of grout	A	B	C	D	E	R <sup>2</sup>
Without admixture*	-0.25	1.26	0.67	-1.29	0.51	0.833
Superplasticizer	-12.75	-25.27	39.03	0.50	0.39	0.860
Expanding admixture	-11.54	-23.20	36.12	0.52	0.48	0.960
Combination of superplasticizer and expanding admixture	9.82	-7.41	-1.37	-1.39	0.42	0.855

\*Does not include water/cement ratio = 0.38 at all cement sand ratios

*Table 3 Regression coefficients of equation (5)*

Type of grout	A	B	C	D	R <sup>2</sup>
Without admixture*	-49.67	-0.44	38.63	0.150	0.724
Superplasticizer	39.97	0.36	-32.28	0.100	0.800
Expanding admixture	-4.30	-0.30	1.82	0.658	0.721
Combination of superplasticizer and expanding admixture	162.65	1.15	132.28	0.108	0.680

### 2.5.5 The modulus of elasticity

The modulus of elasticity of two stage concrete is slightly higher than that of conventional concrete because of point-to-point contact of the coarse aggregate and is mainly affected by the mechanical properties of stone aggregate. Extensive laboratory tests on the two-stage concrete using three different types of coarse aggregate (rounded, crushed, and mixed) and three different grout proportions ( $w/c = 0.45, 0.50,$  and  $0.55$ ;  $c/s = 1/1.5, 1/1,$  and  $1/0.8$ ) were performed to describe the concrete mechanical properties, Abdelgader and Górski (2003). The results obtained and their statistical analysis enables formulation of the following comments. The linear part of the stress-strain curve may reach as much as 40–60% of the compressive strength of the specimens as shown in Figure 2.

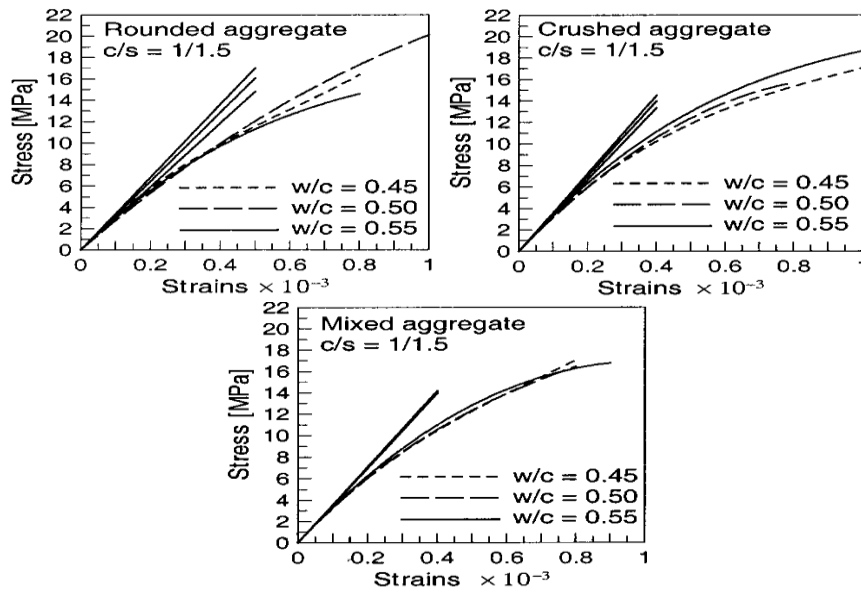


Figure 2: Graphical presentation of estimating two stage concrete modulus of elasticity

The static modulus of elasticity ( $E_{TSC}$ ) as a function of the compressive strength of the two-stage concrete ( $f_c'$ ) is derived. See Equations 6a, 6b and 6c.

For rounded aggregate:

$$E_{TSC} = 28.7 + 0.080 \times f_c' \quad (\text{GPa}) \quad (6a)$$

For crushed aggregate:

$$E_{TSC} = 33.9 - 0.049 \times f_c' \quad (\text{GPa}) \quad (6b)$$

For mixed aggregate:

$$E_{TSC} = 34.9 - 0.090 \times f_c' \quad (\text{GPa}) \quad (6c)$$

The strength limit values in Eq. (6) are:  $22 \text{ MPa} \leq f_c' \leq 32 \text{ MPa}$

The two-stage concrete static modulus of elasticity, for the examined types of aggregates and grout proportions, is mainly influenced by the mechanical characteristics of the aggregates—i.e., the compressive cylindrical strength, surface texture, and grading. The type of grout has a significant effect. The characteristic mechanical properties of the two-stage concrete can be explained by the specific stress distributions, which occur mainly through the particles of coarse aggregate (skeleton of the aggregate). Relationships between modulus of elasticity and its compressive cube strength are shown in Figure 3.

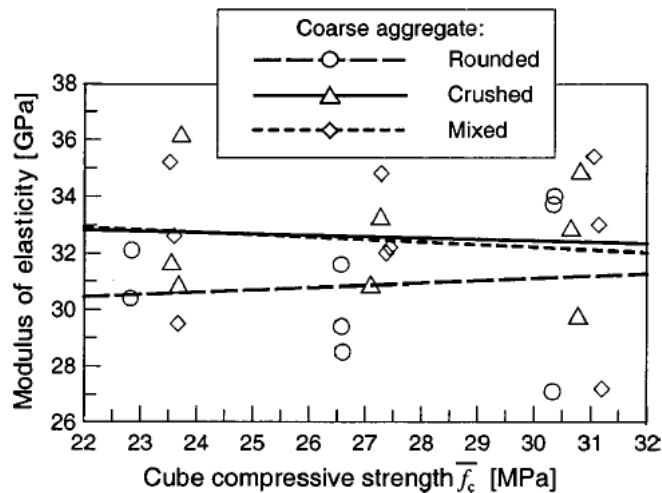


Figure 4: Relationships between modulus of elasticity and its compressive cube strength

### 2.5.6 Shrinkage

TSC differs from conventional concrete in that it contains a higher percentage of coarse aggregate, Abdelgader(1996). Because of the point-to-point contact of the coarse aggregate as shown in Figure 1, drying shrinkage of TSC is about one-half that of conventional concrete. This property in TSC needs more research work to be clarified.

### 2.5.7 Segregation of the aggregate

The risk of having aggregate segregation is completely avoided in TSC since the coarse aggregate is placed before adding the other remaining concrete constitutes. In the case of using the two-stage concrete method for underwater concreting, the dense grout displaces upwards the water available between aggregate particles, producing a high aggregate/cement ratio concrete with point-to-point aggregate contact.

### 2.5.8 The cold joints

In the case of normal concrete, the cold joints should be executed in specific locations, but in the case of two-stage concrete these can be executed in any location, because the coarse aggregate pieces cross the joint, bond and shear, which in the majority of cases, will be adequate.

## 3. The uses of two-stage concrete

TSC can be used for many applications just as:

- TSC is suitable for use in effecting repairs and making additions to concrete structures.



- Where placement by conventional methods is difficult (e.g., massive reinforcing steel).
- When low-volume change of the repair concrete is required to avoid cracking caused by excessive tensile stresses in the overlay concrete because of dry shrinkage and restraint provided by existing concrete.
- Where underwater placement is necessary because dewatering is difficult, expensive, or impractical and water conditions permit. In the case of using two-stage concrete method for underwater concreting, the water and air being displaced upward by the rising grout front. Injection is continued until a free washout of grout is emitted from the top of the pour and the voids between the aggregate is completely filled by the cement grout.

## 4. Rock-filled concrete

Rock-filled concrete (RFC) is a new type of concrete for massive concrete construction works based on the technology of Self –Compacting Concrete (SCC). It is produced by pouring ready – mixed SCC into the voids of large blocks of rock with the minimum size 300 mm in the formwork. The SCC fills the void space between the blocks due to its good fluidity and segregation resistance, and thereafter the mix sets to form the RFC mass. Figure 4 shows, RFC as a combination of consolidated SCC and large blocks, Xuehui, Mmiansong, Hu zhou and Feng (2009).

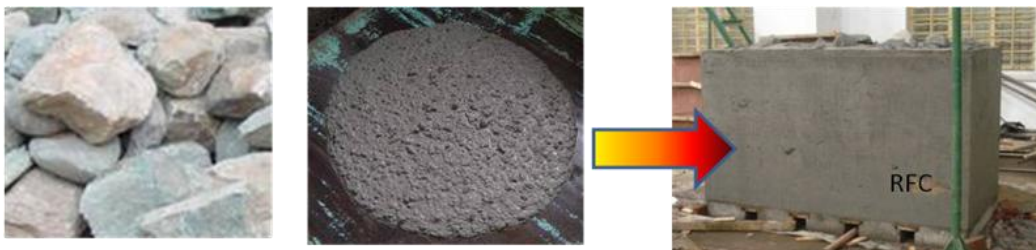


Figure 4: Rock-filled concrete

### 4.1 Advantages of using rock-filled concrete

There are many advantages for the employment of RFC in practical structures

- Low heat of hydration because the use of low cement content which makes it more easier to ensure temperature control
- Allowing continuous pouring of SCC to reduce the construction time, Concrete Society Technical Report (2008).

- No need for compaction by using SCC results in compaction being ensured independent of the quality of construction work, Newman and Seng (2003).
- Simplifying the aggregate production and concrete mixing machinery contributing to cost reduction
- Using the rock-block mass as skeleton of concrete results relatively little drying and shrinkage
- Reducing noise as well as energy consumption contributes to lower emissions of the greenhouse gas (GHG) carbon dioxides and also sulphur dioxide.

## **4.2 Applications of rock-filled concrete**

RFC has been put practical use in the following hydraulic projects:

### **4.2.1 Experimental dam construction**

RFC was first used in a gravity dam in a reservoir project in Beijing. The 13.5 m high, 2,000 m<sup>3</sup> gravity dam was finished in 2005.

### **4.2.2 Auxiliary dam in Baoquan pumped storage project**

After successfully employed in experimental gravity dam RFC was applied in part of the auxiliary dam of the upper reservoir in Henan Baoquan pumped storage project. The dam was designed as a 50000 m<sup>3</sup>, masonry construction, such as low construction with RFC to solve the problems in the practical masonry construction, such as low efficiency and low construction quality. It was finished in 2006 and the picture of the site during RFC construction is shown in Figure 5.

### **4.2.3 Gully backfill in Baoquan pumped-storage project**

After finishing the RFC construction on part of the auxiliary dam at Baoquan, most of the engineers involved, including those with the owners, designer and construction, understood more about the benefits of RFC and came to an agreement on using RFC instead of conventional vibro-compacted in the gully backfill project. The total volume of the backfill project was 130,000 m<sup>3</sup>, and approximately 50,000 m<sup>3</sup> of them was constructed with RFC.

### **4.2.4 Caisson backfill in Xiangjiaba hydropower project**

RFC was also employed in the Caisson backfill in Xiangjiaba hydropower project, which would be the third largest hydropower station in China. Approximately 70,000 m<sup>3</sup> of RFC had been constructed in the Caisson backfill project and it was finished in the end of 2007. See Figure 5.



Figure 5 : Caisson backfill and Auxiliary dam examples

## 5. Conclusions

- The cost of two stage concrete is almost 40% less than the cost of normal concrete. This is related to the reduction of cement content by 30% and there is no need for compaction or vibrating of concrete.
- The risk of having aggregate segregation is completely avoided since the coarse aggregate is placed before adding the other remaining concrete constitutes.
- Bond of two-stage concrete is excellent because the grout used to consolidate the pre-placed aggregate penetrates surface irregularities and pores to establish initial bond.
- In the case of normal concrete, the cold joints should be executed in specific locations, but in the case of two-stage concrete can be executed in any location, this is because the strength of two-stage concrete depends specifically on the coarse aggregates itself.
- The use of Rock Filled Concrete gives many advantages related to quality, cost and environment considerations.
- The RFC gives low heat of hydration because the use of low cement content which makes it easier to ensure temperature control.
- RFC Allows continuous pouring of SCC and reduce the construction time
- In RFC method there is no need for compaction as using SCC results in compaction being ensured independent of the quality of construction work
- Simplifying the aggregate production and concrete mixing machinery contributes to cost reduction
- Using the rock-block mass as skeleton of concrete results relatively little drying and shrinkage

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