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Review

Critical overview of two-stage concrete: Properties and applications

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HIGHLIGHTS

- Two-stage concrete (TSC) technology and history are presented.
- The materials specifications for TSC are outlined.
- The engineering properties of TSC and its long-term performance are compiled.
- Future research on TSC and need for further development are discussed.

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ABSTRACT

Two-stage concrete (TSC), also known as preplaced aggregate concrete, is a special type of concrete that is produced using a unique procedure which differs from that of conventional concrete. In TSC, coarse aggregate particles are first placed in the formwork and voids between them are subsequently injected with a special cementitious mixture. TSC has been successfully used in many applications, such as underwater construction, casting concrete sections congested with reinforcement and concrete repair. This paper provides a critical overview of TSC, including its development history, material specifications, engineering properties and long term-performance. This critical overview of the TSC state-of-the-art should enhance the understanding of its behaviour, thus paving the way for wider implementation of its use in today's concrete industry.

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1. Introduction

Two-stage concrete (TSC) is defined as concrete produced by placing coarse aggregate particles in the designed formwork, then filling the internal gaps with a special grout mixture. TSC is known worldwide under different terms that are listed in Table 1. These different names of TSC reflect the difference in its production methods. For instance, in the United Kingdom it is known as "Colcrete" as they mix the grout in a colloidal mixer before injecting it into the coarse aggregate.

Generally, the TSC grouting process can be done either by gravity or by a pumping process [1]. In the gravity process (i.e. penetration method), the grout is poured on the top surface of the preplaced aggregate and allowed to penetrate through the aggregate body to the bottom of the section under its own weight. However, this method is particularly useful for grouting thin sections with a depth of less than 300 mm [12 in.] [2]. In the pumping process, the grout is pumped into the aggregate mass from the bottom through a network of pipes as illustrated in Fig. 1. The minimum coarse aggregate size plays a major role in selecting the suitable grouting method. For instance, the gravity process can be successfully used for aggregates with a minimum size of 50 mm [2 in.], while the pumping method is preferred with lower void content coarse aggregate (i.e. finer aggregates) [3].

TSC differs from conventional concrete in several aspects. First, all ingredients of conventional concrete are mixed together and then placed in the formwork, while in TSC the grout ingredients are mixed separately and then injected into the pre-placed aggregate mass as mentioned earlier. Second, TSC has a higher coarse aggregate content (about 60% of the total volume) than that of conventional concrete (about 40% of the total volume) [4]. Hence, TSC can be considered as a skeleton of coarse aggregate particles resting on each other, leaving only internal voids to be filled with grout [4]. Conversely, in normal concrete the aggregates are rather dispersed. Therefore, TSC has a specific stress distribution mechanism at which the stresses are transferred through contact areas between aggregate particles (Fig. 2) [5]. These stresses can be responsible for the fracture and tearing of aggregate particles away from the grout [6].

Table 1
Different names of two-stage concrete.

TSC name	Refs.
Colcrete	[4,14]
PolCrete	[4,11]
Naturbeton	[11]
Arbeton	[11]
Prepacked concrete	[1,9,10]
Preplaced aggregate concrete	[11]
Grouted aggregate concrete	[2,11]
Injected aggregate concrete	[11]
Rock-filled concrete	[12]

The TSC technique provides a solution for the coarse aggregate segregation problem, especially for heavy weight aggregate concretes, through pre-placing the aggregates in the formwork. Furthermore, TSC does not need compaction, vibration or any other consolidation processes to achieve a dense structure, which in turn reduces its production cost. The formwork used for TSC must be strong and sufficiently tight to resist the lateral pressure induced by the injected grout and to minimize its leakage. Consequently, the cost of TSC formwork is about one-third higher than that used for conventional concrete [7]. On the other hand, TSC is considered as the most cost-effective technique for underwater concreting compared to other techniques [8]. However, the construction of TSC requires special skill and experience that most contractors do not have. Therefore, this paper provides useful information that can assist contractors and engineers in producing TSC.

2. History of two-stage concrete applications

In 1930s, TSC was developed after the invention of the high-speed colloidal mill mixer, which made the manufacture of highly stable flowable grout feasible [13]. Initially, TSC was introduced as a repair technique for existing concrete infrastructure such as bridges and tunnel linings. The first use of TSC was in 1939 for the rehabilitation of the Santa Fe railroad tunnel, California [11]. In 1950, Japanese construction companies bought rights to use TSC in their construction projects [11]. Since then, TSC has been widely used in many construction applications. For example, about 383,000 m^3 [13,525,520 ft^3] of TSC were used to construct the 34 piers of the Mackinac Bridge [11,16].

On the other hand, the production process of TSC makes it one of the preferable technologies for the construction of nuclear power plants since the coarse aggregate is pre-placed. Hence, very heavy minerals incorporated within aggregates (e.g. magnetite,

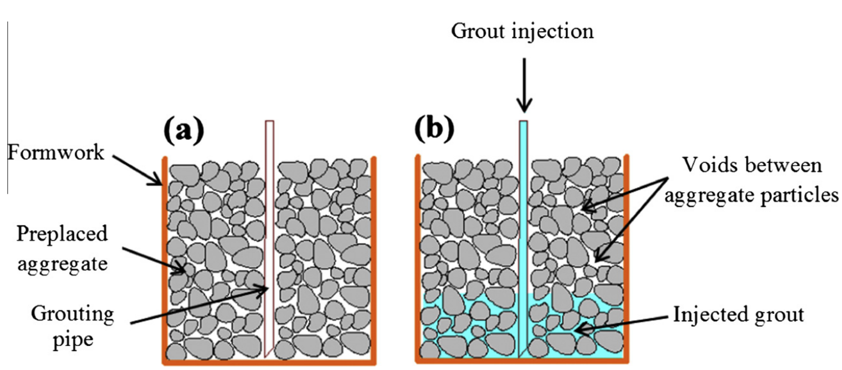

Fig. 1. TSC grout pumping process: (a) coarse aggregate placement and (b) grout pumping through pipes.

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