CONCRETE REPAIR USING TWO STAGE CONCRETE

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Abstract: During the last decades, 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. Two-stage (Pre-placed aggregate) concrete is produced by placing coarse aggregate in a form and later injecting a cement-sand grout, to fill the voids between aggregate particles. For economic and technical reasons two-stage concrete is particularly used for construction and repair of mass structures, especially foundations, underwater constructions, and in all kinds of construction with closely spaced reinforcement. This paper presents some implementations of using such concrete in repair works, some formulae and guidelines which describe the mechanical parameters of this concrete such as modulus of elasticity, tensile strength and drying shrinkage. It was found that the modulus of elasticity and splitting tensile strength of two-stage concrete is equivalent or higher than that of conventional concrete at the same compressive strength.

Keywords: two-stage concrete, modulus of elasticity, strength, shrinkage, splitting tensile.

1. Introduction

Concrete is one of the important materials for construction. It was concerned for several scientific studies and program researching to develop it's technologies for obtaining improved concrete by distinct properties in the same time achieving economical cost at production stage or at long term (durability). Therefore, one of the manners to improve the techniques of concreting, was the two-stage (Pre-placed aggregate) concrete (TSC). TSC gets its name from the method used for placement. Formwork is constructed and the stone aggregate fraction is densely placed inside the mould. The stone aggregate is washed and screened just prior to placement to remove all fines. Grout is then injected through the forms to provide the matrix. Grouting is begun at the bottom of the form of TSC. The formwork must be stronger and tighter than is normally suitable for conventional concrete. Stronger, tighter mould minimizes grout leakage and resists the lateral pressure that occurs as the grout is injected under pressure. In TSC no consolidation process, as for example vibration is needed. TSC provides better durability than normal concrete (NC). In other words, repair to accomplish the damage is best done by the use of TSC. First, the weak parts are removed by chipping, usually to depth behind the reinforcement. If the steel bars are so badly rusted as to require replacement, the unsuitable sections are cut out and new pieces spliced to the old bars, usually by welding. Next, the concrete is washed cleaned, coarse aggregate is then placed behind the forms as they are erected. Finally, special grout is pumped into the aggregate beginning at the bottom. This grout when used to make TSC concrete should be highly fluid. Therefore, it penetrates intimately all of the minute indentations in the rough surface of the old concrete to establish perfect initial bond [1]. It is most probably to say the cost of TSC is less than of the conventional concrete by (20–40) %, hence this cost reduction is reflected on the repair process [2].

1.1. Site applications

Typically, TSC is used on large repair projects; particularly where underwater concrete placement is required or when conventional placing of concrete would be difficult. Typical applications have included underwater repair of stilling basins, dams, bridges, abutments, and footings. TSC has also been used to repair beams and columns in industrial plants [1], Figure 1. For example, in Poland large-scale two-stage concreting was tested in two applications, namely while laying foundations for an 18story building in Gdnask (Poland) (about 350 m^3), and the repair of damage to a water dam in Czchow near Cracow (Poland) (about 400 m^3) underwater concreting, on the Dunajec River. In both cases good technological and economical results were obtained [2].

1.1.1. Jackers and collars

Jacketing is the process whereby a section of an existing structural member is restored to original dimensions or increased in size by encasement in new Portland cement or polymer-modified Portland cement concrete. A steel reinforcement cage is constructed around the damaged section into which shotcrete or cast-in-place concrete is placed [3]. Collars are jackets, which surround only a part of a column or pier and typically are used to provide increased support to the slab or beam at the top of the column. The form for the jacket may be temporary or permanent and may consist of timber, corrugated metal, pre-cast concrete, rubber, fiberglass, or special fabric, depending on the purpose and exposure. The jacket form is placed around the section to be repaired, creating an annular void between the jacket and the surface of the existing member. The form should be provided with spacers to assure equal clearance between it and the existing member. A variety of materials including conventional concrete and mortar, epoxy mortar, grout, and latex modified mortar and concrete have been used as encasement materials. Techniques for filling the jacket include pumping, tremie, or two-stage concrete [3].

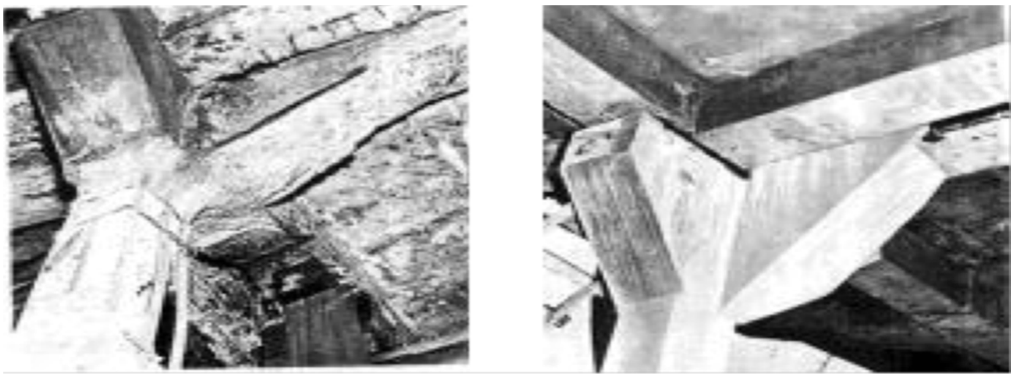

Fig. 1. TSC used in column repair

1.1.2. Joint construction

Cold joints are formed within the mass of TSC when pumping is stopped for longer than the grout remains plastic. When this occurs, the insert pipes should be pulled to just above the grout surface before the grout stiffens, and rodded clear. To resume pumping, the pipes should be worked back to near contact with the hardened grout surface and pumping resumed, slowly for a few minutes to create a mound of grout around the end of the pipe. Because the coarse aggregate pieces cross this joint, bond and shear in most cases will be adequate. However, if the grout bleeds excessively, some laitance may collect on the grout surface portion of the joint and weaken the bond [3].

2. Objective of the study

This paper presents the availability of this method in conventional construction and especially in the patch repairs of the deteriorated concrete. It is necessary to say, one of the important points in patch repair theory is to replace deteriorated concrete with suitable material that has excellent mechanical properties to avoid similar defects in the same portions at long term in future.

3. Experimental results

As it is mentioned before, this study is a result of analysing many experimental data in order to obtain better understanding for the behaviour of TSC as supplementary method instead of NC for production of construction and repair material. Therefore, the following properties of TSC are presented.

3.1. Drying shrinkage of TSC

TSC differs from conventional concrete in that it contains a higher percentage of coarse aggregate [4]. Because of the point-to-point contact of the coarse aggregate Figure 2, drying shrinkage of TSC is about one-half that of conventional concrete. Since the aggregate is pre-placed and the grout is pumped under pressure, segregation is not a problem and virtually all substrate voids will be filled with mortar. These factors make TSC an ideal material for applications where considerable congestion of reinforcement or other embedment, or difficult access exists. The ability of the grout to displace water from the voids between aggregate particles during injection makes this material particularly suitable for underwater repairs [2]. Since most repairs are made on older Portland cement concrete that will not undergo further significant shrinkage, the repair material must also be essentially shrinkage-free or be able to shrink without losing bond. Shrinkage of cementitious repair materials can be reduced by using mixtures with very low water-cement ratios or by using construction procedures that minimize the shrinkage potential.

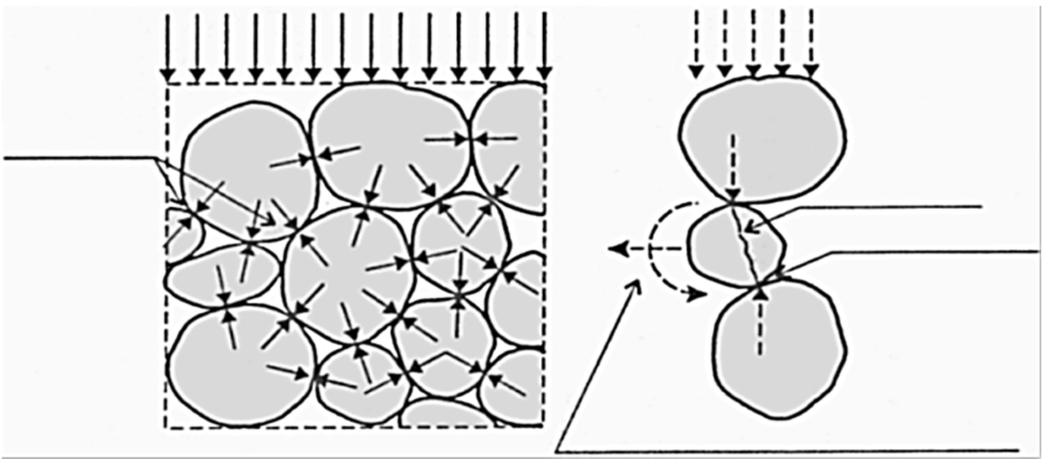

Fig. 2. Shows contact points in TSC

The drying shrinkage of normal concrete is caused by physical-chemical properties of the cement paste. In TSC the grout fills only the cavities, and the basic mass of concrete is the stone skeleton only. The drying shrinkage can practically occur in the vicinity of cavities. Under ordinary conditions and proper curing, the lower drying shrinkage of TSC is attributed to the high content of stone aggregate and the grain-to-grain contact as said above. Less drying shrinkage may results in reduced cracking repair overlays.

TSC shows good stability of volume and low calorific value, which is of great importance in massive structures. Some results for drying shrinkage of NC and TSC are presented in Table 1. The small values of contraction can be explained by the continuity of skeleton, individual grains of stone filling are in close contact with one another, which results in their small negative deformation.

Table 1: Drying shrinkage of TSC and NC at different ages

Age (days)	**Type of Concrete**	**Shrinkage (-) 10^{-5}**	**Temperature in Mass Concrete + °C**
7	NC TSC	5 2.5	38 20
28	NC TSC	2.5 8	32 25
56	NC TSC	-2 17	23 18
80	NC TSC	-8 8	17 15
100	NC TSC	-15 2.5	15 15

3.2. Modulus of elasticity of TSC

The The experimental data analysis and the statically obtained relations allow for formulating the relationship between the modulus of elasticity and the compressive strength of TSC, in which the compressive strength is calculated according to equation (1):

$$\overline{f_c} = \beta_0 + \beta_1 + \overline{\bar{f}_g^{\beta_2}} \text{ (MPa)} \qquad (1)$$

where: f_c _ compressive strength of TSC, f_g _ compressive strength of grout and β_0, β_1 and β_2 are constants assumed for the specific aggregate [5].

The modulus of elasticity of the TSC is mainly affected by the physical properties of the stone aggregate. The influence of the content of grout in the concrete is rather meaningless. It has been observed that the same factors that affect the compressive strength also alter the elastic modulus of TSC, see Figure 3. The initial tangent modulus of elasticity of TSC (ETSC) determined as a function of strains can be calculated from equation (2):

$$E_{tsc}(\varepsilon 1) = \frac{d\sigma'}{d\varepsilon_1} = 3 \cdot a(\omega, \varsigma) \cdot \varepsilon 1^2 + 2b(\omega, \varsigma) \cdot \varepsilon 1 + c(\omega, \varsigma) \text{ (GPa)} \qquad (2)$$

where: a, b & c – are regression coefficients [6] and ω, ς are coefficients depending on water-cement and cement-sand ratios [6].

For initial tangent modulus of elasticity assume that $\varepsilon_1 = 0$. The tangent elastic modulus is obtained from the analysis of the stress-strain curves for each type of stone aggregate and the mix proportions [7].

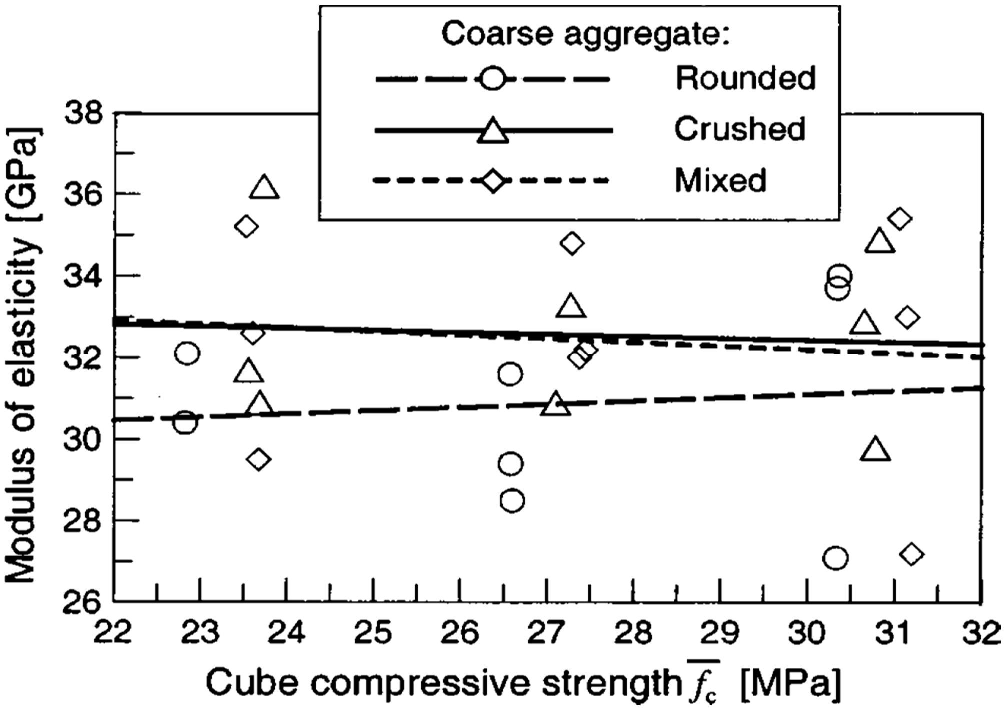

Fig. 3. Relationships between modulus of elasticity of two-stage concrete and its compressive strength

3.3. Tensile strength of TSC

3.3.1. Split test

The split tensile strength of TSC was investigated at 28 days [8]. The splitting tensile data obtained for TSC are presented in Table 2. The test results of the split tensile strength were apparently high in TSC.

Table 2: Split tensile strength of two-stage concrete at 28 day

Water to Cement Ratio (W/C)	Cement to Sand Ratio(C/S)	Split Tensile (lab.) MPa	Split Tensile (theoretical) MPa
0.40	2:1	3.35	3.37
0.45		3.14	3.16
0.50		2.83	3.01
0.55		2.27	2.81
0.40	1:1	3.34	3.13
0.45		3.02	2.90
0.50		2.86	2.70
0.55		2.53	2.60

3.3.2. Double-punch

This test method for measuring tensile strength of concrete is an indirect tension test. In this test method, a compressive load is applied to a concrete cylinder along its axis through two steel punches placed on the top and bottom surfaces of the cylinder [8]. The double-punch tensile strength test results obtained for TSC are presented in Table 3.

Table 3: Double-punch tensile strength of two-stage concrete at 28 day

Water to Cement Ratio (W/C)	Cement to Sand Ratio (C/S)	Double-Punch (lab.) MPa	Double-Punch (theoretical) MPa
0.40	2:1	2.38	2.29
0.45		1.81	2.11
0.50		1.78	2.00
0.55		1.73	1.83
0.40	1:1	2.36	2.09
0.45		2.09	1.90
0.50		2.05	1.74
0.55		1.49	1.66

4. Conclusions

TSC is very efficient material for repairs of deteriorated concrete elements.

The drying shrinkage of TSC is lower than that of NC. Where the reduced shrinkage is due to the point-to-point contact of the stone aggregate particles.

The modulus of elasticity as a function of compressive strength of the TSC is elaborated. The modulus values for specific types of aggregate can be described by the linear constant functions.

The relationship between tensile strength and compressive strength, referred in this paper shows that the tensile strength of TSC increases with the increase in its compressive strength. This relationship can also help the engineers in designing the TSC structures.

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