History and Overview of Self Compacting Grout and Concrete: Properties and Applications

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Abstract

Two-stage concrete (TSC) 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. 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. As the name would suggest it is produced through a two-stage process. Firstly, washed coarse aggregate is placed into the formwork in-situ. Later a specifically designed grout is introduced into the form from the lowest point under gravity pressure to fill the voids, cementing the aggregate into a monolith. TSC is particularly useful for underwater construction, placement in areas with closely spaced reinforcement and in cavities where overhead contact is necessary, repairs to concrete and masonry where the replacement is to participate in stress distribution, heavyweight (high-density) concrete, high-lift monolithic sections, and in general, where concrete of low volume change is required. This paper presents some implementations of using such concrete in repair works, some formulae and guide lines which describe the mechanical parameters of this concrete such as modulus of elasticity, tensile strength and drying shrinkage.

Keywords: Modulus of elasticity, Compressive-strength, Tensile-strength, Aggregate, Drying shrinkage.

1. INTRODUCTION

Placing concrete in general is a challenging task for construction engineering, due to the risk of segregation and bleeding or washout of concrete constituents specially, when placement occurs in difficult places such as: concrete repairing or underwater applications. Thus, the quality of concrete produced is highly influenced by its placement technique during manufacturing and casting [1, 2]. Placement techniques involve free-fall gravitational placement, pumping, belt conveyors, tremie, and preplaced aggregate concrete ……etc. The goal when applying any of these techniques is to place concrete into the formwork with minimum segregation, minimum honeycombing and maximum possible homogeneity of the concrete constituents [3]. Concrete shrinkage and consequently shrinkage cracking has been a growing concern. Minimizing shrinkage can take place by adequate mix proportions, thorough curing and the use of shrinkage compensating cement [4, 5]. It was approved that using non-traditional concrete in engineering applications has been considered as an efficient solution to overcome challenges of limitations of the use of normal conventional concrete. Such new types of concretes which have been developed and produced are completely dissimilar from the conventional concrete in the method of mixing, handling, pouring, consolidation, behaviours, cost… etc. Based on the technology of ready-mixed self-compacting concrete (SCC), a type of non-conventional concrete has been introduced and named as: two-stage concrete (TSC) [6 to 8]. Two-stage (pre-placed aggregate) concrete (TSC), unlike normal concrete (NC), is made by first placing the coarse aggregate in the formwork and then injecting a grout consisting of sand, cement and water to fill the voids between the aggregate particles (see Figure 1). The most significant difference of TSC from conventional concrete is that TSC contains a higher percentage of coarse aggregate compared to conventional concrete; because TSC is produced by depositing coarse aggregate directly into the forms, where there is a point-to-point contact, instead of being contained in a flow-able plastic mixture as in conventional concrete. Because of this, the properties of TSC depend on the coarse aggregate, more than its other constituents. As a result of this, the modulus of elasticity of TSC is found to be slightly higher, and its drying shrinkage is less than half that of conventional concrete [4]. Investigations on some properties of TSC will demonstrated and discussed through this paper in the next subtitles.

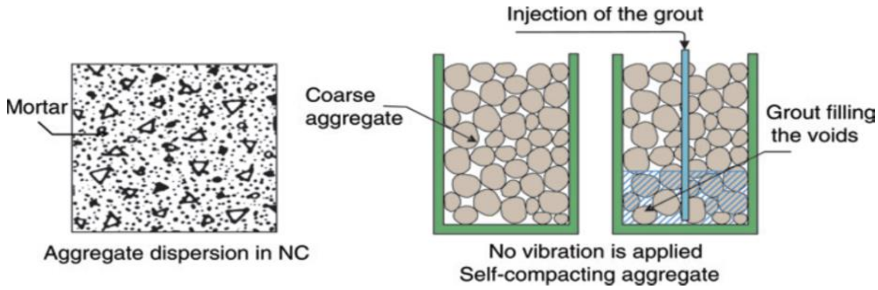

Figure 1. Theory of concreting

2. PREPARATION OF EXISTING CONCRETE SURFACES

If the TSC is used to repair surface defects, or cast as an addition to an existing concrete structure, in order to establish a good bond between the new TSC and the existing old concrete, the surface of the existing concrete must be cleaned very carefully by removing all deteriorated concrete till the sound concrete is reached, and a space which is at least four times the maximum coarse aggregate size should be provided behind the existing reinforcement, or the new reinforcing to be added [4]. One of the other special properties of TSC is its excellent bonding ability when it is added to an existing roughened concrete. This ability of TSC comes from two reasons:

1.The grout can penetrate through the surface irregularities and pores on the existing concrete surface, and establish an initial bond.

2.The low drying shrinkage of TSC minimizes the interfacial stresses taking place upon drying.

3. EXPERIMENTAL PROGRAM–PART (I)

3.1. MATERIALS

The cement used was ordinary Portland cement Type I with 28-days compressive strength of 41 MPa and Blaine fineness of approximately 3500 cm2/g. Cement properties confirmed with ASTM standards [9]. The fine aggregate used was natural beach sand of specific gravity 2.63 and maximum size of 1.18. Coarse aggregate used was angular basalt of specific gravity 2.69, crushing value of 20.74%, abrasion value of 23.81%, and absorption value of 1.96 %. Both fine and coarse aggregate properties checked in accordance with ASTM standards [10]. The super plasticizer used in the grout was a naphthalene- formaldehyde derivative, trade name 'SikaMent-163' and was mixed at the rate of 2% by weight of cement. The expanding agent, trade name 'Intraplast-Z' was an aluminium powder-based admixture; this was also used at the rate of 2% by weight of cement.

3.2. MIXTURE PROPORTIONS AND SAMPLE PREPARATION

Three different proportions of c/s, 0.5: 1, 1: 1 and 1.5: 1, with varying ratios of w/c, 0.38, 0.55 and 0.80, as shown in Table 1. A total of 360 standard concrete cylinders (150 mmx300 mm) were tested in unconfined compression and tensile strength at 28 days.

Table 1- Grout mix proportions

Water : Cement Ratio (W/C)	Cement : Sand Ratio (C/S)	Cement	Sand
		Kg/m^3	
0.38	0.5	295	590
	1	421	421
	1.5	525	350
0.55	0.5	282	564
	1	407	407
	1.5	507	338
0.80	0.5	265	530
	1	396	396
	1.5	489	326

3.3. CONSISTENCY OBSERVATIONS AND DISCUSSION

To measure consistency both a flow cone and flow table tests were conducted [11,12] as shown in Figure 2. Fluidity results are presented in Figure 3 and 4.

Figure 2. Flow cone and flow meter setup

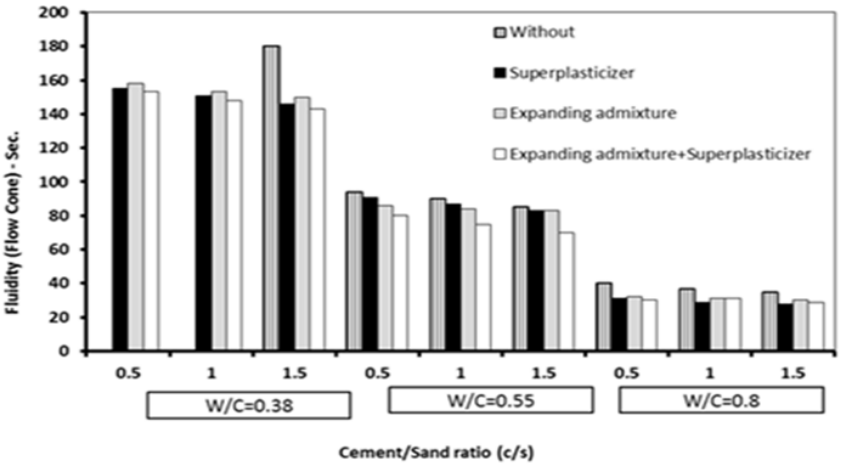

Figure 3. Flow cone test results

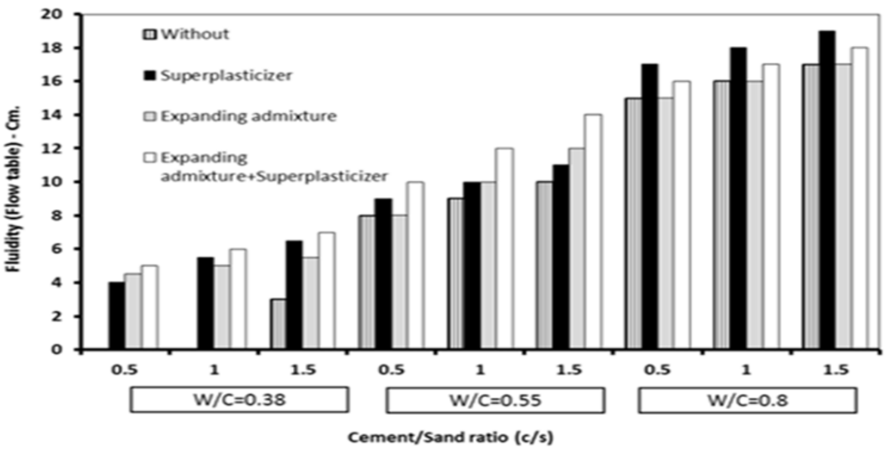

Figure 4. Flow table test results

Tests on consistency demonstrated that the higher c/s ratio of 1.5 required much more water, where the flow cone depends on the time of flow while the flow table depends on the propagation of flow [11]. For example, the w/c ratio 0.38 in the plain grout and expanding admixture at all c/s ratios is the minimum ratio to obtain grout; it was not possible to penetrate all voids in the aggregate skeleton.

3.4 COMPRESSIVE STRENGTH OBSERVATIONS AND DISCUSSION

The compressive strength fc` of TSC was tested with and without admixture at 28 days. Sample of results is shown in Table 2. Based on the results, a relation for fc` has been assumed, according to the design algorithm presented in reference [13]. Equation (1) is an empirical equation derived from the experimental data for prediction of compressive strength of TSC (fc`) in (MPa) as the following:

$$f_c` = a + (b) \times w/c + (c) \times (w/c)^{d} + (e) \times (c/s) \quad (1)$$

Where: fc` represents the estimated compressive strength of TSC, w/c is the water-to-cement ratio and c/s is the cement-to-sand ratio. Table 3 shows the values of the regression coefficients. Compressive strength without admixture was found to be lower than compressive strength with admixture (super plasticiser). The possible reason for this decrease in strength was the low fluidity of the grout. When high fluidity of grout was used (achieved by using super plasticiser at high w/c ratios), the compressive strength of TSC did not increase. The quality of TSC depends not only on the strength of grout but on its ability to expand while fluid and remove the traces of bleed water that collect under aggregate particles [12]. With this idea of an expanding admixture, a blend of special metallic aluminium powder expansion agent was used in the grout. The strength data shows that when using the expanding admixture the compressive strength of TSC was significantly increased. Super plasticiser and expanding admixture were used together among the four types of grouts. The compressive strength was found to have the highest strength. This could be attributed to the following: (a) higher fluidity of grout using super plasticiser (which enables the grout to fill all the voids between aggregate particles) (b) expansion effect of grouts using expansion admixture to minimise bleeding and settlement of grout.

Table 2- Average compressive strength results

W/C Ratio	C/S Ratio	Average Compressive Strength (MPa)			
		Without	Super plasticizer	Expanding Admixture	Expanding and Super plasticizer
0.38	0.5	--------	15.59	15.26	18.68
	1.0	--------	17.39	16.54	18.96
	1.5	--------	18.53	18.01	19.47
0.55	0.5	15.65	18.19	16.56	19.06
	1.0	17.57	19.49	18.01	19.75
	1.5	20.49	20.59	19.67	22.72
0.80	0.5	13.69	14.39	17.06	18.16
	1.0	15.07	15.79	16.08	18.75
	1.5	16.01	16.31	19.10	19.37

Table 3- Regression results for equation (1)

Type of Grout	Regression Coefficients					Correlation Coefficients
	a	b	c	d	e	
Without Admixture*	-3.67	11.20	3.96	-1.79	3.70	0.833
Super plasticizer	43.90	-32.55	-3.27	-1.68	2.24	0.944
Expanding Admixture	-14.31	-39.38	68.45	0.47	2.63	0.891
Expanding and Super plasticizer	-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

3.5. TENSILE STRENGTH OBSERVATIONS AND DISCUSSION

The tensile strength of TSC was investigated at 28 days. Table 4 shows the values of experimental tensile strength. Equation (2) is an empirical equation derived from the experimental data for prediction of tensile strength of TSC (ft) in (MPa). Table 5 shows the values of the regression coefficients.

$$f_t = A + (B) \times (w/c) + (C) \times (w/c)^{D} + (E) \times (c/s) \quad (2)$$

Table 4- Average tensile strength results

W/C Ratio	C/S Ratio	Average Tensile Strength (MPa)			
		Without	Super plasticizer	Expanding Admixture	Expanding and Super plasticizer
0.38	0.5	--------	1.74	1.62	1.84
	1.0	--------	1.98	1.86	2.06
	1.5	--------	2.38	2.16	2.54
0.55	0.5	2.18	2.42	2.36	2.78
	1.0	2.44	2.66	2.58	2.88
	1.5	2.61	2.84	2.82	3.36
0.80	0.5	1.80	2.20	2.26	2.38
	1.0	2.30	2.42	2.58	2.56
	1.5	2.40	2.32	2.70	3.36

Table 5- Regression results for equation (2)

Type of Grout	Regression Coefficients					Correlation Coefficients
	A	B	C	D	E	
Without Admixture*	-0.25	1.26	0.67	-1.29	0.51	0.833
Super plasticizer	-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
Expanding and Super plasticizer	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

3.6. DRYING SHRINKAGE OBSERVATION AND DISCUSSION

Because of the point-to-point contact of the coarse aggregate, drying shrinkage of TSC is about one-half that of conventional concrete [4]. 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. Less drying shrinkage may result 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 6. 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 6- Drying shrinkage of TSC and NC

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

4. EXPERIMENTAL PROGRAM – PART (II)

This part of the paper presents the results of some experimental tests conduct by the author and others [13] to study the behavior of TSC under loading and derive relation between elastic modulus and the compressive strength.

4.1. STRESS-STRAIN PROCEDURE, OBSERVATIONS AND DISCUSSION

Stress-strain tests conducted using cylinder specimens (196 mm in diameter and 392 mm in length) of the same nine different grout proportions and types of aggregate. There were prepared 81 specimens in total (three cylinders per composition). During the loading procedure, the vertical deformations were measured on three sides of the specimen versus the axial force increment. On the basis of these results, the stress and appropriate strain values were calculated. The results obtained from the cylinder specimens were used to derive the stress-strain relations and the modulus of elasticity for the two-stage concrete. As the linear part of the stress-strain curves obtained for each type of the two-stage concrete reached at least 40% of its compressive strength, the initial tangent modulus of elasticity was derived. The tangent line is drawn along the stress-strain curve at its starting point (see some examples presented in Figure 5).

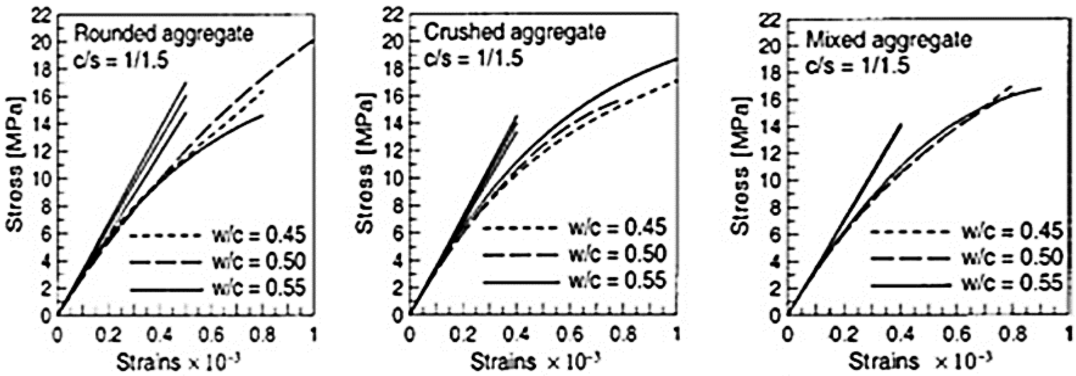

Figure 5. TSC estimated modulus of elasticity for round aggregate

The values of the module are computed from stress-strain curves for the examined cases of aggregate types and grout mixes, and are given in Table 8. From the other hand, the experimental data analysis and the statistically obtained stress-strain relations allow for formulating the relationship between the static modulus of elasticity and the compressive strength of the two-stage concrete (f_c`) at 28 days as shown in Table 8. The compressive strength limit values are between 22 MPa and 32 MPa.

Table 8- Computed modulus of elasticity (Using formulas and stress-strain curves)

W/C	C/S	Modulus of elasticity (GPa)			Derived formulas for modulus of elasticity (GPa)	
		Round aggregate	Crushed aggregate	Mixed aggregate		
0.45	1/1.5	34.0	34.9	35.4	Round aggregate	$E_{TSC}=28.7+0.080*f_c$`
0.50		28.5	33.3	34.8		
0.55		32.1	36.2	35.2		
0.45	1/1.0	33.7	32.9	33.0	Crushed aggregate	$E_{TSC}=33.9+0.049*f_c$`
0.50		29.4	30.9	32.0		
0.55		30.4	31.7	32.6		
0.45	1/0.8	27.1	29.8	27.2	Mixed aggregate	$E_{TSC}=34.9+0.090*f_c$`
0.50		31.6	-	32.2		
0.55		-	30.9	29.5		

5. CONCLUSIONS

- As the method of placement in TSC is entirely different from that of NC, a suitable admixture is necessary to satisfy the requirement for the pumping ability of grout. The expanding admixture was found to be the most suitable admixture as it provided higher fluidity with minimum bleeding.
- The compressive strength and tensile strength of TSC was tested with and without admixture at 28 days for all grout proportions. On the basis of the results, a correlation between the strength and grout proportions was statistically derived.
- The stress-strain relationships for different grout mixes (water/cement ratios and cement/sand ratios) do not show a big difference. Linear relations can estimate the initial stress-strain curves. This may result from the stresses distributed mainly by the particles of stone aggregate (skeleton of stones). The specific way of stress transmission may also contribute to the initiation and propagation of cracks.

- The modulus of elasticity as a function of compressive strength of the two-stage concrete is elaborated. The modulus values for specific types of aggregate can be described by linear constant functions. The obtained equations can help engineers to design the two-stage concrete.
- It is proved that the crushed aggregate is better than the rounded aggregate for designing the two-stage concrete. The crushed aggregate makes it possible for a better contact between the grains of the aggregates than the rounded stones.
- The authors believe that there are many aspects of TSC that require clarification through further theoretical and experimental studies such as: energy dissipation, failure mechanism and cracking, shrinkage, creep and other time dependent deformations.

6. References

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