MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE

BY

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ABSTRACT

Self-compacting concrete (SCC) is a new concept for fresh and hardened concrete and refers to the ability of fresh mixtures to deform and undergo change in shape and pass through obstacle under its own weight without exhibiting segregation and to ensure proper filling of the formwork.

An experimental investigation was conducted to study the properties of hardened self-compacting concrete (SCC) and its bond strength. In this study, the hardened properties of (SCC) containing different sizes of coarse aggregate (20, 14 and 10 mm) were experimentally investigated and compared with those of conventional concrete. The effect of different dosage of viscosity enhanced admixture (VEA) (0, 0.5, 1, 1.5 and 2% of cement weight) on the properties of hardened concrete are also discussed in this work. The mechanical properties of hardened self-compacting concrete (SCC) were investigated in terms of standard compressive strength and splitting tensile strength. Bond strengths were also determined for reinforcing bars embedded in concrete according to the Rilem test specification.

Results from these tests show that higher size of coarse aggregate was found more suitable to ensure high compressive and tensile strength than concrete made by smaller size of aggregate. A significant increase in bond strength was found when using higher size of coarse aggregate especially when comparing (SCC) to ordinary concrete. Also, higher values of compressive, tensile and bond strengths were obtained when using viscosity enhanced admixture (VEA) with a ratio of 1.5% of the cement weight.

Manuscript received from Dr. A.G.Abdel - Rahman

Accepted on : 21 / 12 / 2001

Engineering Research Journal Vol 25,No 2, 2002 Minufiya University, Faculty Of Engineering , Shebien El-Kom , Egypt , ISSN 1110-1180

INTRODUCTION

Concrete is one of the essential structural materials for constructing the infrastructure of the society. However, careful placing by skilled workers on site is vital for constructing durable and reliable structures. In other words, reduced durability resulting from improper placement is a serious defect in concrete manufacture. To overcome this defect, it is necessary to develop concrete, which is not affected by workmanship during placing or self-compactable concrete requiring no consolidation. The self-compactable concrete can not only produce durable and reliable concrete structures, but also save labor, eliminate the consolidation noise, lead to the innovation of construction systems, and realize the modernization of concrete construction. Many new construction methods and materials that have recently been developed will find wider applications if they are combined with self-compactable concrete [1-5].

Self-compacting concrete can be used for filling non-congested sections in order to accelerate the progress of construction without mitigating mechanical properties and durability that can result from segregation and bleeding. The lack of strict performance criteria for basement construction and the need for basement construction and the need for speedy construction often result in the placement of highly-fluid concrete so that the discharge of concrete can proceed quickly with minimum need for consolidation. Often, such concrete is proportioned with high water content to be "self-leveling and self consolidating". However, such structures often exhibit low in-situ impermeability and crack resistance. As a result, basements can be damp and have poor visual quality to be used as permanent surfaces. The use of properly designed (SCC) can maintain the high workability necessary for the ease of placement while ensuring adequate in-situ engineering properties and durability [6-12].

Providing adequate concrete stability during placement the concrete should have a proper stability while in a stationary state until it hardens in order to minimize the migration of free water and bleeding and the segregation of suspended solid particles. This is important to secure homogeneous properties of the hardened concrete. The lack of stability of highly flowable concrete can weaken the interface between the aggregate and the cement paste and increase the tendency to develop local microcracking that can increase permeability and reduce mechanical properties. Bleeding can also result in some accumulation of porous cement paste under the lower half of horizontally embedded reinforcement and under the ribs of vertically positioned bars. The surface settlement of fresh concrete, which is related to the segregation of concrete, can reduce the effective projection of concrete lugs and contribute further to the reduction in bond strength [13]. Ensuring adequate stability is especially critical in deep structural elements where highly flowable concrete can exhibit segregation, bleeding, and surface settlement that reduce strength, stiffness, bond to reinforcing steel, and durability. The use of viscosity-enhancing admixture (VEA), along with adequate concentration of high range water reducing (HRWR), can ensure high deformability and adequate stability leading to greater filling capacity and better homogeneity of hardened properties [14-15]. At 3 days, the compressive strength for self-compacting concrete (SCC) and ordinary concrete (NC), which have the same W/C ratios and curing conditions was similar. However, the compressive strength of the specimens cured in a moist condition was higher with age than that of the specimens cured in air conditions. At 28 days, the difference of the compressive strength for (SCC) due to curing conditions was about 10 %, while that for (NC) was more than 18 %. It can be concluded that the effect of curing conditions on the compressive strength of self-compacting concrete is less than that of ordinary concrete. In the 28 days, splitting tensile strength of self-compacting concrete was about 8-10 % of the compressive strength, and this ratio was similar to that of ordinary concrete with the same compressive strength. Also, the ratio of splitting tensile strength and compressive strength was independent of the loading age [16-17].

In this Investigation the mechanical behavior of self-compacting concrete with various sizes of coarse aggregates (gravel) and different dosages of viscosity enhanced admixtures (VEA) are discussed.

EXPERIMENTAL PROGRAMME

A total of 45 cubes, 15×15×15 cm and cylinders of 15 cm in diameter and 30 cm in length were studied to determine the compressive and tensile strengths of self-compacting concrete (SCC), respectively as shown in Table 1. Also 45 cylinders containing deformed reinforced steel bars with 16 mm effective diameter were used to evaluate the bond strength. Three specimens were cast and tested for each mix.

Materials

Well-graded quartzite sand with a fineness modulus of 2.72 was employed. The relative density values of the coarse aggregate (gravel) and sand were 2.62 and 2.56, respectively, and their absorption rates were 0.8 and 1%, respectively. Ordinary Portland Cement (OPC) from Suez factory was used and complied with the Egyptian standard specifications. The cement content and water cement ratio were kept constant at 450 kg/m^3 and 0.4, respectively. Clean tap water free from impurities was used for mixing the concrete. A viscosity agent with branch name Sika Viscocrete-5-400 concrete admixture has been used in order to allow deformability without segregation. The amount of viscosity agent was 0, 0.5, 1, 1.5 and 2% of cement weight. The absolute volume method recommended by ACI committee was used to determine the required quantities of materials for the test mix. The volume of coarse aggregate was 50% of the total volume of solids in concrete.

Experimental Methods

The dry constituents (cement, sand and gravel) were mixed for at least 60 seconds before the water and the admixtures have been added. The mixing time after water was added was at least four minutes. The properties of SCC in fresh state were determined by different methods such as slump flow, V-funnel and L-box methods, and by the slump cone for ordinary concrete as mentioned previously in the work by A.G. Abdel–Rahman and M.M. Balaha [18]. The second phase consisted of determining the hardened properties of SCC. The standard cubes measuring 150 mm length were demoulded one day after casting and then cured in tap water until testing was carried out. The splitting tensile strength was determined at 28 days on the cylinders measuring 150 × 300 mm. The cubes and cylinders were tested for all SCC and reference mix by using 1000 KN hydraulic testing machine. The bonded length of reinforced bar was properly cleaned to ensure an adequate bond with concrete. Average bond stresses were evaluated by carrying out the pull-out test using a 1000 KN hydraulic testing machine. The test was terminated when a pull-out failure occurred, the reinforced steel began to yield or the surrounding concrete cover failed in tension. The average bond strength was calculated as follows:

$$\sigma_b = \frac{P}{\pi d L}$$

Where P, d and L correspond to the applied load, bar diameter and anchored length, respectively.

TEST RESULTS AND DISCUSSION

There are number of tests that were carried out on hardened concrete to study the effect of nominal maximum size of coarse aggregate (20, 14 and 10 mm) and different dosages of VEA (0.0, 0.5, 1, 1.5 and 2% by cement weight) on the mechanical behavior of SCC.

Influence of Maximum Aggregate Size on Properties of Hardened SCC

Figure (1) shows the development of compressive strength as a function of different nominal maximum size of coarse aggregate and different dosages of VEA of self-compacting concrete (SCC). Concrete containing nominal maximum size of gravel equal to 10 mm showed a lower compressive strength than the concrete containing nominal maximum size of gravel equal to 20 mm. For example, the compressive strength was increased by about (9%) for a maximum aggregate size change from 10 to 14 mm, and increased by about (4%) for a change in size of coarse aggregate from 14 to 20 mm. These results were reported for 1.5% dosage of viscosity enhanced admixture (VEA). The increase in the compressive strength with the increase in maximum aggregate size may be explained as follows: Presence of small aggregates (10 mm) in the SCC produces high stress concentration under loading, resulting in an increase in rate of crack propagation. Consequently a reduction in compressive strength of SCC occurs. On the other hand, presence of large size aggregates (20 mm) in SCC allow stresses to be distributed over a larger area, reducing the stress concentration and therefore, lower rates of crack propagation and higher compressive strength were recorded.

The splitting tensile test was carried out according to BS 1881-52 [19] on a standard cylinder, tested on its side in diametrical compression. Figure (2) shows the results of the ultimate splitting tension obtained in the laboratory for the different nominal maximum size (N.M.S) of gravel used and different dosages of VEA. It is noticed that the same trend of results of the compressive strength was obtained here for the splitting tensile strength. For example, increasing the size of coarse aggregate from 10 to 14 mm resulted in an enhancement in splitting tensile strength by about (18%) and increasing the size of coarse aggregate from 14 to 20 mm resulted in an enhancement in splitting tensile strength by about (2%). These results were recorded for a dosage of VEA = 1.5%.

The bond strength is different with different (N.M.S) of aggregates and different dosages of VEA as can be seen in Fig. (3). As shown in the figure, the bond strength increases as N.M.S of gravel increases. For example, the bond strength increases by about (20%) when N.M.S of gravel changes from 10 to 14 mm and increases by about (5%) when N.M.S of gravel changes from 14 to 20 mm. These values were also taken for 1.5% dosage of VEA. The improvement in the bond strength may be explained as follows: Increasing size of coarse aggregates leads to high fluidity of SCC which supply enough matrix for covering the aggregates and embedded steel bar and resulting in an enhancement in bond strength. It can also be seen from Figs. (1-3) that the strengths (compressive, tensile and bond) of SCC was greater than that of the reference mix.

Influence of Dosages of VEA on Properties of Hardened SCC

Figure (4) explains the effect of increasing VEA on the compressive strength of SCC for different dosages of VEA and different maximum aggregate size of gravel. As shown from the figure, the compressive strength increases rapidly when the amount of VEA increases until it reaches 1.5% dosage. As an example, the compressive strength increases by about (5%) when the dosage of VEA increases from 0.0 to 0.5%, increases by about (4.5%) when the dosage of VEA increases from 0.5 to 1%, and increases by about (3%) when the dosage of VEA increases from 1 to 1.5% by cement weight. On the other side, when the dosage of VEA was 2%, the compressive strength was decreased when compared to that occurring in case of VEA = 1.5% but still considerably greater than that of the reference mix. These results were given when N.M.S of gravel was 20 mm. This behavior can be explained as follows: When increasing the dosage of VEA until 1.5% this improved the workability and cohesiveness of SCC leading to a reduction in bleeding, segregation and surface settlement, which in turn reduced the defects resulting from increasing porosity. Accordingly, the compressive strength of SCC increased due to increasing the dosage of VEA. Beyond the 1.5% dosage (at 2%), an adverse effect was obtained as was reflected in the fresh concrete properties in terms of less homogeneity of the concrete constituents and the appearance of signs of bleeding and segregation [18] and was also shown in the compressive strength results of Fig. 1.

Figure (5) gives the relation between the splitting tensile strength and different dosages of VEA with different N.M.S of aggregates. From the results, it was found that as the dosage of VEA increases from 0.0 to 0.5%, the tensile strength increases by about (13%), as the dosage of VEA increases from 0.5 to 1% the tensile strength increases by about (5%) and as the dosage of VEA increases from 1 to 1.5% the tensile strength increases by about (2%). The same trend of results is noticed when considering the values of bond strength as shown in Fig. (6), where the increase of dosage VEA until 1.5% led to an increase in the viscosity and cohesion friction between the SCC and steel bar, and accordingly, an increase in the bond strength of concrete. The relatively higher strength of the SCC is believed to be mainly due to having no porosity in the SCC.

CONCLUSIONS

Based on the test results from this study the following conclusions can be drawn:

1- Self-compacting concrete (SCC) showed a better performance than the conventional concrete. About 12%, 16% and 40% increases were obtained for the compressive, tensile and bond strengths, respectively.
2. The increase of maximum size of aggregates from 10 to 20 mm and incorporation of a moderate concentration of viscosity enhanced admixture (VEA) (1.5%) resulted in a net increase of compressive, tensile and bond strengths.
3. The optimum strength results were obtained at 1.5% dosage of VEA. However, results at 2% dosage were still greater than these obtained by the conventional concrete
4. At 1.5% dosage of VEA, about 9% increase was obtained in the compressive strength with the 20 mm aggregate more than when the 10 mm aggregate was used.
5. The splitting tensile strength of SCC was increased by about 18% when 20 mm aggregate was used in comparison to the strength obtained with 10 mm aggregate, keeping the 1.5% dosage of VEA.
6. The bond strength of SCC was increased by about 20% when 20 mm aggregate was used in comparison to the strength obtained with 10 mm aggregate, keeping the 1.5% dosage of VEA.

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Table (1): Layout of Tested Specimens

Beam No.	Nominal Maximum Size of Gravel (mm)			Viscosity Enhanced Admixture (VEA) %					Type of Test
	20	14	10	0	0.5	1	1.5	2	
1	√			√					Compressive Strength Cubes 15×15×15 cm
2	√				√				
3	√					√			
4	√						√		
5	√							√	
6		√		√					
7		√			√				
8		√				√			
9		√					√		
10		√						√	
11			√	√					
12			√		√				
13			√			√			
14			√				√		
15			√					√	
16	√			√					Tensile Strength Cylinders 15 × 30 cm
17	√				√				
18	√					√			
19	√						√		
20	√							√	
21		√		√					
22		√			√				
23		√				√			
24		√					√		
25		√						√	
26			√	√					
27			√		√				
28			√			√			
29			√				√		
30			√					√	
31	√			√					Bond Strength Cylinders 15 × 30 cm
32	√				√				
33	√					√			
34	√						√		
35	√							√	
36		√		√					
37		√			√				
38		√				√			
39		√					√		
40		√						√	
41			√	√					
42			√		√				
43			√			√			
44			√				√		
45			√					√	

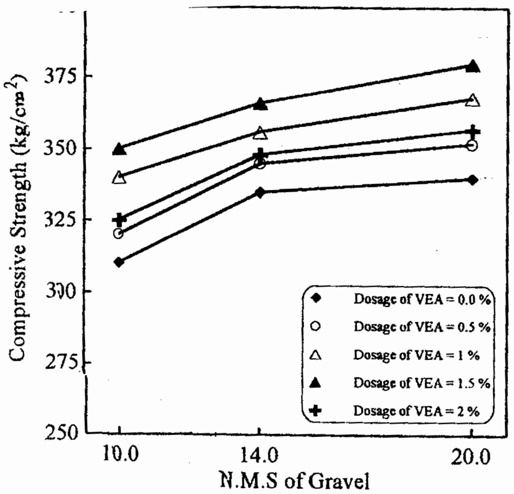

Fig. (1): Compressive Strength vs N.M.S of Gravel

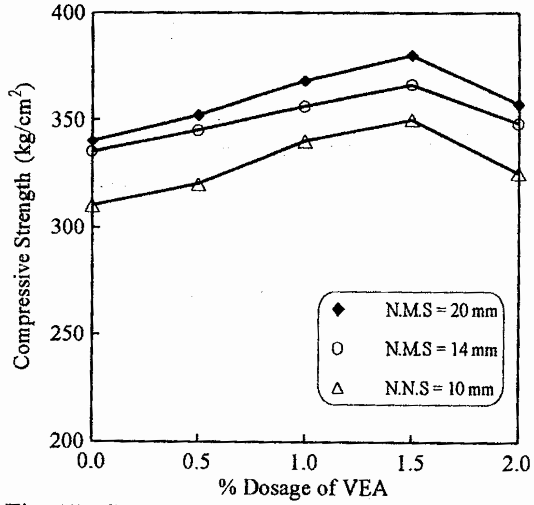

Fig. (4): Compressive Strength vs % Dosage of VEA

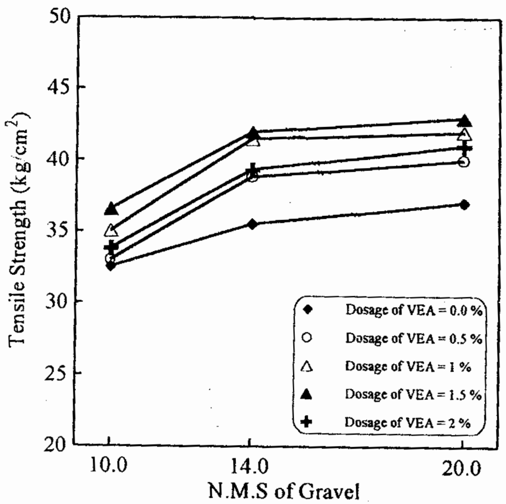

Fig. (2): Tensile Strength vs N.M.S of Gravel

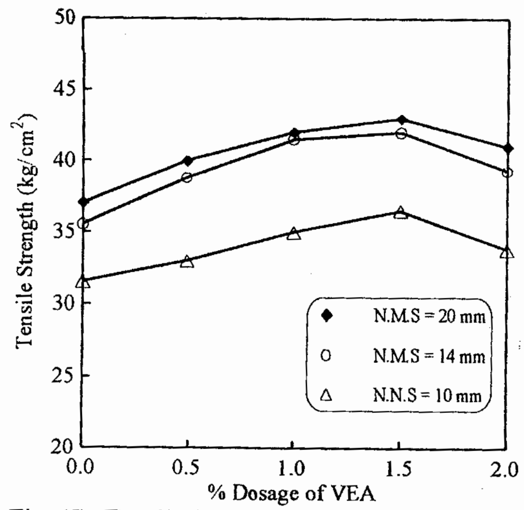

Fig. (5): Tensile Strength vs % Dosage of VEA

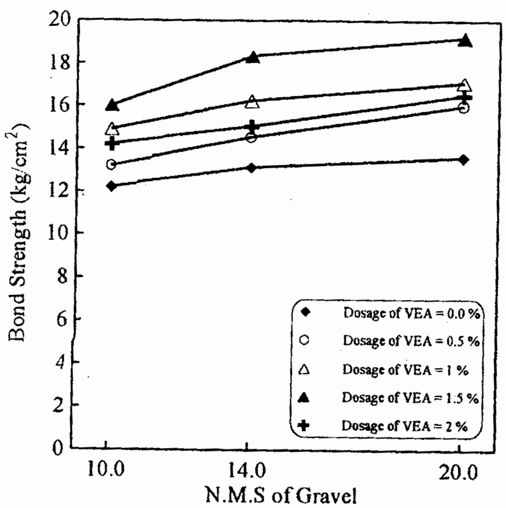

Fig. (3): Bond Strength vs N.M.S of Gravel

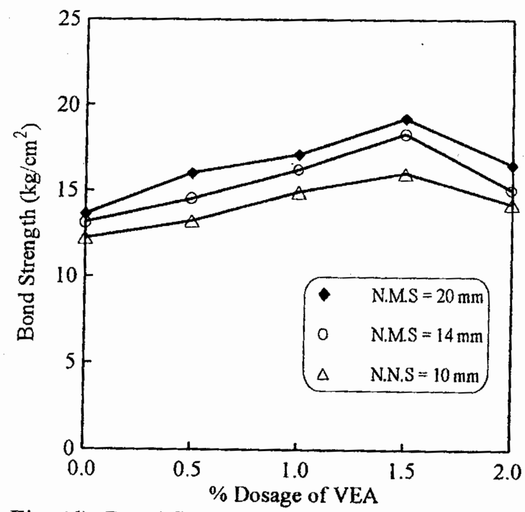

Fig. (6): Bond Strength vs % Dosage of VEA

الخواص الميكانيكية للخرسانة ذاتية الدمك

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مدرس

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الملخص

تعتبر الخرسانة ذاتية الدمك نوعية جديدة ذات أداء متميز حيث تحقق انسيابية عالية للحصول على خرسانة طازجة ومتصلدة ذات جودة عالية. هذه النوعية من الخرسانة يحدث لها انتشار بسهولة نتيجة تأثير وزنها فقط داخل الفرم الخرسانية دون حدوث أي نضح أو انفصال لمكونات الخرسانة.

الهدف من هذا البحث هو دراسة تأثير كلا من حجم الركام وكمية المادة المضافة من إضافات تحسين اللزوجة على الخواص المتصلدة للخرسانة ذاتية الدمك وأيضا تأثيرها على مقاومة الربط. وقد تم استخدام ثلاثة أحجام مختلفة من حجم الركام وهى ٢٠ ، ١٤ ، ١٠ مم وأيضا خمس نسب من إضافات تحسين اللزوجة وهى صفر ، ٠,٥ ، ١ ، ١,٥ ، ٢% من وزن الأسمنت الحر. وقد تم دراسة الخواص الميكانيكية للخرسانة ذاتية الدمك لمعرفة كلا من مقاومة الضغط والشد وكذلك مقاومة الربط بين أسياخ حديد التسليح وهذه النوعية من الخرسانة.

وقد أظهرت النتائج فى هذا البحث أن زيادة حجم الركام تسبب فى زيادة كلا من مقاومة الضغط والشد للخرسانة بمقارنته بالركام ذات الحجم الصغير ، وأيضا وجدت زيادة واضحة فى مقاومة الربط فى حالة استخدام ركام ذات حجم كبير (٢٠ مم) لهذه النوعية من الخرسانة بمقارنتها بالخرسانة العادية ، وكذلك وجد أن نسبة ١,٥ % من إضافات تحسين اللزوجة من وزن الأسمنت الحر كانت من أفضل النسب التى أعطت زيادة واضحة لكلا من مقاومة الضغط والشد والربط للخرسانة ذاتية الدمك.