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Fresh and Hardened Properties of Highly Workable Concrete (HWC)

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ABSTRACT

Casting concrete, especially for narrow sections have congested steel, requires suitable compaction energy by vibrators. The production of a highly workable concrete can save and reduce the energy required for compaction, the site man-power, the noise levels, and the time of construction as well as to produce a durable concrete elements. In this research work, eight highly workable concrete mixes, two self compacting concrete mixes and four normal conventional concrete mixes were fabricated with different types and percentages of constituent materials. Slump, compaction factor, vibrated L-box, and segregation tests were conducted to detect the workability and segregation resistance of the concrete mixes. The hardened properties of the highly workable concrete were checked and compared with those of the normal conventional concrete and self compacting concrete. Test results demonstrated that, the use of a high workable concrete in construction industry offer products with enhanced characteristics as well as could be economic.

Keywords: workability, compaction, slump, segregation, mechanical properties

1 INTRODUCTION

Compaction of concrete is essential to remove the internal voids and to expel the entrapped air from concrete. Adequate workability is required to achieve full compaction and maximum density of the concrete, with reasonable compacting efforts. By the early 1990's, Japan has used self compacting concrete that does not require vibration to achieve full compaction (Hajime, 2003). Nevertheless, self compacting concrete is not widely used as it needs high quality control for the concrete production, transporting, and casting to ensure the self compacting property and high resistance to aggregate segregation. In case of small projects in remote areas, especially in developed countries, non skilled workers usually use rotary mixers to produce a high workable type of concrete. However, the concrete mix should not be too wet for easy compaction as high percentage of water cement ratio highly reduces the concrete strength.

(Per,2009) studied the high workable concrete composition and reported that; fine-to-coarse aggregate ratio should be optimized to increase the concrete workability with emphasis on minimizing viscosity and achieving high cohesiveness to prevent bleeding and segregation rather than simply minimizing materials costs. (Hajime, 2003) mentioned that highly viscous paste is required to avoid the blockage of coarse aggregate when concrete flows through obstacles. When concrete is deformed, paste with a high viscosity also prevents localized increases in internal stress due to the approach of coarse aggregate particles. They reported that the high deformability of concrete can be achieved only by the employment of a super-plasticizer, keeping the water-powder to a very low value.

This research work aims to produce highly workable concrete mixes using different percentages of fine to coarse aggregate, fine powder content (lime powder - silica-fume), and super-plasticizer. Similar to the SCC mixes, in order to get high workable concrete, the design of the HWC mixes should contain fine powders and super-plasticizer. The HWC mixes must have dynamic stability during mixing, transportation, handling and placement. The fresh and hardened properties of the highly workable concrete were investigated and compared with those of the normal conventional concrete and self compacting concrete. The experimental test results demonstrated that a high performance high workable concrete can be produced and simply compacted without the fear of concrete blockage or aggregate segregation.

2 EXPERIMENTAL STUDY

Several trial mixes were fabricated and tested to produce eight highly workable concrete (HWC) mixes, two self compacting concrete (SCC) mixes and four normal conventional concrete (NCC) mixes. The slump, compaction factor, vibrated L-box, and aggregate segregation tests were carried out to define the fresh concrete properties. The compressive strength, the splitting tensile strength, and the flexural strength were detected for all concrete mixes to identify their hardened properties.

2.1 Material Properties

2.1.1 Cement

Ordinary Portland cement produced by Assiut cement factory (Cemex) was used to fabricate the concrete mixes and the tested concrete elements. The surface area of the cement is 3200 cm^2/gm. The specific gravity and the 28-days compressive strength of the cement are 3.15, 385 kg/cm^2, respectively.

2.1.2 Fine and coarse aggregate

Natural sand and gravel from local quires in Egypt were used to fabricate the concrete mixes. The average value of specific gravity for both sand and gravel was 2.6. The maximum nominal size of the gravel used to fabricate the conventional and the high workable concrete mixes is 20 mm. The maximum nominal size of the gravel used to fabricate SCC mixes is 14 mm. It is of important to mention that, the aggregate was washed and left in the open air for 24 hours before mixing.

2.1.3 Lime stone powder

In order to increase the workability, fine lime stone powder (particle size smaller than 0.125 mm) was used at different percentages of the cement weight to fabricate highly workable and self compacting concrete. The specific gravity of the lime stone powder is 2.7.

2.1.4 Silica fume

Silica fume dust is collected by filters as a by-product of the melting process to produce silicon metal and ferro-silicon alloys. It consists of spherical particles of amorphous silicon dioxide and is highly pozzolanic. The specific gravity of silica fume is 2.17.

2.1.5 Super-plasticizer

Super-plasticizer (Addicrete BVF), having high range water reducer without retarding effect, was used to fabricate the concrete mixes. It enables high reduction in water cement ratio and consequently increases the concrete strength. The specific gravity of the super-plasticizer is 1.15.

2.2 Concrete mixes

Concrete mix proportions of the highly workable concrete (HWC), normal conventional concrete (NCC), and self compacting concrete (SCC) are presented in table (1). The cement content of the concrete mix ($M_{7\text{-HWC}}$ and $M_{8\text{-HWC}}$) was 350 kg/m^3. The remaining concrete mixes had 400 kg/m^3 cement content. For the high workable concrete, the super-plasticizer content ranged from 2.00% to 2.28% by the weight of cement. In case of self compacting concrete, the super-plasticizer content was 2.5% by the weight of cement. The normal conventional concrete mixes did not contain super-plasticizer. The water cement ratio for the highly workable concrete ranged from 0.38 to 0.44, the water cement ratio for the self compacting concrete ranged from 0.42 to 0.44. In order to get adequate workability for the normal conventional concrete, the water cement ratio ranged from 0.45 to 0.55

The experimental variables were the type of concrete, the cement content, the water cement ratio, the silica fume content (0~5% of the cement mass), the lime stone powder content (0~15% of the cement mass), and the sand to gravel ratio. The absolute volume method of concrete mix design was employed to design all the concrete mixes.

Table 1. Concrete mixes

Mix.	Type of concrete	Cement (Kg/m^3)	Water (l/m^3)	W/C	Silica fume (Kg/m^3)	Lime powder (Kg/m^3)	W/P	Sand (Kg/m^3)	Gravel (Kg/m^3)	S : G	Super-plastisizer (Kg/m^3)
$M_{1\text{-HWC}}$	HWC	400	157	0.40	20	--	0.37	910.00	910.00	1 : 1	8
$M_{2\text{-HWC}}$		400	152	0.38	20	20	0.35	906.67	906.67	1 : 1	8
$M_{3\text{-HWC}}$		400	160	0.40	--	40	0.36	899.00	899.00	1 : 1	8
$M_{4\text{-HWC}}$		400	155	0.39	20	20	0.35	774.00	1032.0	3 : 4	8
$M_{5\text{-HWC}}$		400	158	0.40	--	40	0.36	772.47	1030.0	3 : 4	8
$M_{6\text{-HWC}}$		400	160	0.40	20	40	0.35	591.10	1182.2	1 : 2	8
$M_{7\text{-HWC}}$		350	155	0.44	--	35	0.40	744.75	1111.6	2 : 3	8
$M_{8\text{-HWC}}$		350	150	0.43	--	35	0.39	934.66	934.66	1 : 1	8
$M_{1\text{-SCC}}$	SCC	400	166	0.42	20	40	0.36	876.58	876.58	1 : 1	10
$M_{2\text{-SCC}}$		400	185	0.46	20	60	0.39	850.00	850.00	1 : 1	10
$M_{1\text{-NCC}}$	NCC	400	180	0.45	--	--	0.45	580.00	1160.0	1 : 2	--
$M_{2\text{-NCC}}$		400	190	0.48	--	--	0.48	592.00	1184.0	1 : 2	--
$M_{3\text{-NCC}}$		400	200	0.50	--	--	0.50	566.00	1132.0	1 : 2	--
$M_{4\text{-NCC}}$		400	220	0.55	--	--	0.55	540.00	1085.0	1 : 2	--

2.3 Fresh concrete tests

To check its fresh properties, experimental test were carried out on the concrete mixes such as slump, slump flow, compacting factor, vibrating L-box, and aggregate segregation tests.

2.3.1 Slump and slump flow test

Slump test is suitable to give indication about the consistency or the stiffness of the fresh concrete. Slump test was conducted on the normal conventional concrete and the highly workable concrete. The value of the slump and the type of slump (collapse slump, shear slump, true slump) represents the degree of workability of concrete (ASTM C143). For the self compacting concrete, slump flow test is used to assess the horizontal free flow of self compacting concrete. The diameter of the concrete circle and the time (T50) taken for the concrete to reach the 50 cm spread circle were determined. A spread concrete diameter equal 650±50 mm and a time T50 ranges from 2 to 5 seconds are acceptable values for the filling ability of the self compacting concrete (EFNARC, 2002). Slump flow test shows indications for the occurrences of segregation for the concrete mixes. Sever segregation occurs when the coarse aggregate settle in the centre of the pool of concrete meanwhile, the cement paste spread at the concrete periphery.

2.3.2 Compacting factor test

Compacting factor test measures the degree of compaction done by a standard work, which results from falling through two hoppers inside a lower cylinder. This test is more sensitive to low workable mixes than the high workable ones. The compacting factor is measured by the ratio of the density of the mix to the density of the mix fully compacted. The largest value that can be obtained for the compaction factor value is 1, the more workable the mix is, the nearest the compaction factor is to 1.

2.3.3 Vibrating L-Box test

This test is conducted to check the degree of workability of the normal conventional concrete and the highly workable concrete. The L-Box consists of a vertical and horizontal parts separated by a slide gate and a vertical steel reinforcements as shown in Fig. (1). The vibrating L-box test is carried out by fixing the L-box apparatus on a vibrating table and filling the vertical column with concrete. Then, the sliding gate is removed to allow the concrete to flows from the vertical column, under its own weight and due to the vibration, to the horizontal section of the L-Box apparatus. The time taken until the surface of the concrete become flat and horizontal ($H_2/H_1 = 1$) will be recorded.

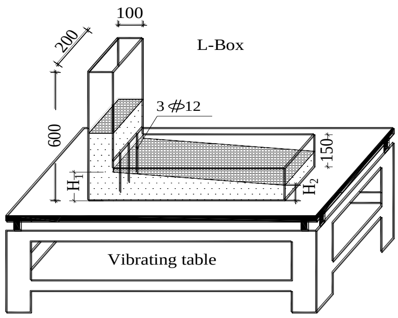

Figure 1. Vibrating L-Box apparatus

2.3.4 Aggregate segregation test

The settlement of the coarse aggregate during compaction is assumed to give an indication about the aggregate segregation. The steps are as following:

1- Steel mould consists of two cubes 10x10x10 cm fixed together, the top without base and the bottom with a fixed base.
2- Filling the mould by two layers of concrete and tamping the concrete 25 times for each layer. The concrete is then compacted using a vibrating table for two minutes.
3- The top part of mould is removed and the concrete in the top and bottom parts are washed separately through sieve No 3/16".
4- The weight of the gravel washed from the top part (w_{gt}) is divided by the weight of the gravel washed from the bottom part (w_{gb}).
5- The ratio (w_{gt}/w_{gb}) gives indication about the segregation resistance of concrete.

2.4 Hardened concrete tests

In order to investigate the mechanical properties of concrete mixes, three concrete cylinders (Diameter = 15 cm and height = 30 cm), three prisms (10x10x50 cm), and six cubes (15x15x15 cm) were cast from every concrete mix. All concrete specimens were cured in a standard condition for 28 days. The cubes were tested under uniaxial static compressive loads, the cylinders were subjected to splitting (Brazilian) test, and the prisms were subjected to four-point flexural loading.

3 TEST RESULTS AND DISCUSSION

3.1 Fresh concrete tests

3.1.1 Slump

Slump test was conducted on the normal conventional concrete and the highly workable concrete. The slump values and the maximum diameter of the concrete mixes are shown in table (2) and Fig (2). Generally, the slump values of the highly workable concrete were higher than those of the normal conventional concrete. True slump values 4 and 6.5 cm were recorded for mixes M_{1-NCC} (w/c=0.45) and M_{2-NCC} (w/c=0.48), respectively. The mix M_{1-NCC} had a low workability and Mix M_{2-NCC} had a medium workability. In order to increase the slump and the workability of the normal conventional concrete, the water cement ratio was increased to become 0.5 and 0.55 for Mixes M_{3-NCC} and M_{4-NCC}, respectively. These mixes showed a collapse type of slump (slump = 18 and 24 cm). The maximum diameter of the concrete mix (M_{4-NCC}) was 54 cm and aggregate segregation was detected by the visual observation which is mainly attributed to the high value of water cement ratio.

The highly workable concrete mixes showed high values of slump and workability. The slump of Mix M_{3-HWC}, M_{5-HWC} and M_{6-HWC} were 22, 23 and 19 cm, respectively. The maximum diameter of these mixes ranged from 35 to 50 cm showing a collapse type of slump without any indications of aggregate segregation, see Fig. (3-a). True slump (from 13 to 17 cm) were recorded for the remaining HWC mixes with a maximum diameter in the range of 25 to 30 cm, see Fig. (3-b).

3.1.2 Slump flow

Table (2) presents the slump flow results of the self compacting concrete mixes. The slump-flow diameter for Mixes M_{1-SCC} and M_{2-SCC} were 60 and 55 cm, respectively. The time T50 ranged from 3’30” to 4’ 20” seconds. The previous mentioned values for the slump flow diameter and the time T50 give good indications about the Passing and filling abilities of the SCC mixes. It is worth to mention that, from the visual observations of the slump flow test there was no indications for the occurrence of segregation in the SCC mixes.

3.1.3 Compacting factor

Because of their high workability, self compacting concrete and highly workable concrete mixes showed high values of compaction factor. The compaction factor of SCC and HWC mixes were in the range of 0.95 to 0.99, see table (2). The composition of the SCC and HWC mixes slightly affected the values of the compacting factor which may be attributed to the low sensitivity of the compaction factor test to the high workable concrete. The compaction factor of the normal conventional concrete mixes M_{1-NCC}, M_{2-NCC}, M_{3-NCC}, and M_{4-NCC} were 0.89, 0.92, 0.98, and 0.98, respectively. The lowest value of compaction factor and workability were recorded for Mix M_{1-NCC} which is attributed to the low water cement ratio (w/c=0.4). Increasing the water cement ratio to 0.5 and 0.55 resulted in an increase for the values of the compaction factor. It is worse to mention that the resistance to aggregate segregation was very low for the NCC mixes that has high values of water cement ratio.

Table 2. Fresh concrete test results

Mix.	Type of concrete	Slump		Slump flow		Compaction factor	Vibrating L-box (sec)	(w_{gt}/w_{gb})
		Slump (cm)	Max. Diameter (cm)	T50 (sec)	Diameter (cm)			
$M_{1\text{-}HWC}$	HWC	16.0	28	--	--	0.98	00:19:84	0.95
$M_{2\text{-}HWC}$		13.0	29	--	--	0.97	00:40:15	0.91
$M_{3\text{-}HWC}$		22.0	35	--	--	0.98	00:12:15	0.85
$M_{4\text{-}HWC}$		16.5	30	--	--	0.99	00:30:73	0.80
$M_{5\text{-}HWC}$		23.0	50	--	--	0.98	00:26:50	0.80
$M_{6\text{-}HWC}$		19.0	37	--	--	0.96	00:40:27	0.85
$M_{7\text{-}HWC}$		14.0	25	--	--	0.95	00:42:75	0.98
$M_{8\text{-}HWC}$		17.0	30	--	--	0.99	00:25:24	0.99
$M_{1\text{-}SCC}$	SCC	--	--	3’ 30”	60	0.99	00:07:78	0.81
$M_{2\text{-}SCC}$		--	--	4’ 20”	55	0.98	00:10:57	0.88
$M_{1\text{-}NCC}$	NCC	4.0	--	--	--	0.89	02:27:50	0.92
$M_{2\text{-}NCC}$		6.5	--	--	--	0.92	01:58:62	0.95
$M_{3\text{-}NCC}$		18.0	--	--	--	0.98	00:50:40	0.80
$M_{4\text{-}NCC}$		24.0	54	--	--	0. 98	00:19:53	0.75

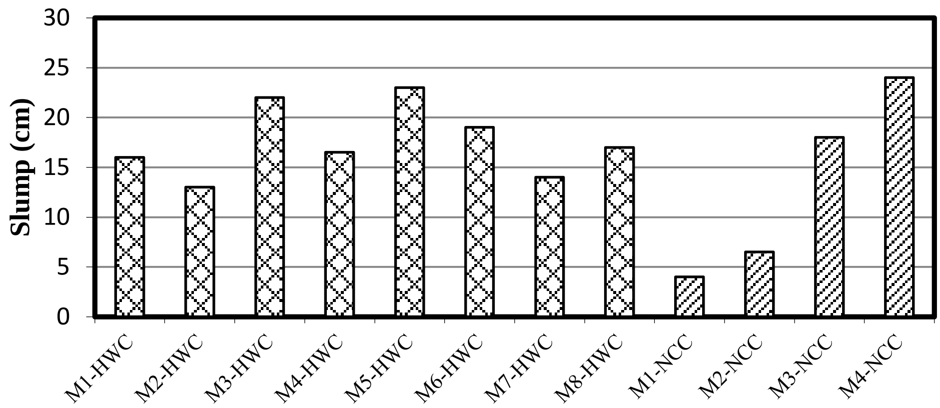

Figure2. Slump values of NCC and HWC mixes

(a) Collapse type. (b) True slump.

Figure 3. Slump of HWC mixes

3.1.4 Vibrating L-Box

The time taken until the surface of the concrete become horizontal in the L-Box was recorded for all concrete mixes as shown in table (2). The lowest time was recorded for the self compacting concrete mixes which elapsed less than 11 seconds for the surface of the concrete to be flat and horizontal. The highly workable concrete took from 12 to 43 seconds for the concrete surface to be horizontal and flat. The NCC mixes ($M_{1\text{-}NCC}$ and $M_{2\text{-}NCC}$) which, have water cement ratio (0.4 and 0.45), were found to take at least two minutes until the concrete surface to be horizontal and flat indicating a low workable concrete. Similar to the highly workable concrete, mixes $M_{3\text{-}NCC}$ and $M_{4\text{-}NCC}$, which have high water cement ratio, recorded about 50 and 20 seconds, respectively. The time recorded for the different concrete mixes showed that, at least 50% of the time and energy required for the concrete compaction can be saved when using highly workable concrete.

3.1.5 Aggregate segregation test

The settlement of the aggregate under its own weight and due to compaction and vibration is considered to give an indication about the aggregate segregation for concrete. The ratio of the weigh of gravel remained in the top part of the mould (w_{gt}) to that in the lower part (w_{gb}) is tested and calculated for all the concrete mixes; see Table (2) and Fig (4). For all concrete mixes, except Mix $M_{4\text{-}NCC}$, the values of (w_{gt}/w_{gb}) were over 80%. This ratio ranged from 0.75 to 0.95 for the NCC mixes and from 0.81 to 0.88 for the SCC mixes. The values of (w_{gt}/w_{gb}) were from 0.80 to 0.99 for the HWC mixes indicating high resistance to aggregate segregation which was proofed by the good distribution for the gravel in the casted elements, see Fig (5). High values of (w_{gt}/w_{gb}) were recorded for the HWC mixes $M_{1\text{-}HWC}$, $M_{2\text{-}HWC}$, $M_{3\text{-}HWC}$, and $M_{8\text{-}HWC}$ that have equal amounts of fine to coarse aggregate per cubic meter (gravel to sand = 1:1). The NCC mix $M_{4\text{-}NCC}$ had the lowest value of (w_{gt}/w_{gb}) indicating a low resistance to aggregate segregation due to its high w/c ratio.

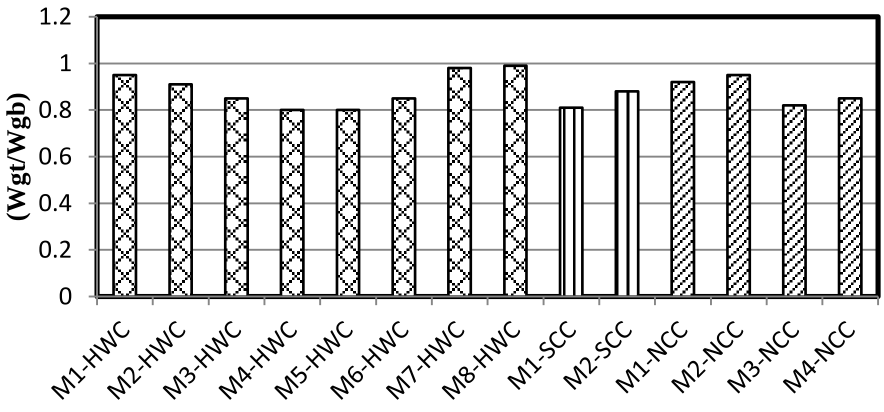

Figure 4. The (W_{gt}/W_{gb}) ratio for all concrete mixes

Figure 5. The distribution for the gravel in the casted elements

3.2 Mechanical Properties of Hardened Concrete

3.2.1 Compressive strength

The 28 days age compressive strength for the concrete mixes are summarized in Table (3) and drawn in Fig (6). The average compressive strength for the highly workable concrete, that have 400 kg/m^3 cement content, was found to be 25% and 80% higher than the average compressive strength of the SCC and NCC, respectively. Increasing the (gravel/sand) ratio and the presence of the silica fume were found to be positively affecting the values of the compressive strength for the HWC. The average compressive strength of the HWC mixes ($M_{7\text{-HWC}}$ and $M_{8\text{-HWC}}$) that contains 350 kg/m^3 cement was found to be 33% higher than the average compressive strength of the NCC mixes ($M_{1\text{-NCC}}$ and $M_{2\text{-NCC}}$) that has 400 kg/m^3 cement content. The improvement for the compressive strength of the highly workable concrete is mainly attributed to the presence of silica fume, super-plasticizer, and lime stone powder as well as the better micro structure and homogeneity of these mixes (Klaus, 2002). On the other hand, the increase of the water cement ratio for mixes $M_{3\text{-NCC}}$ and $M_{4\text{-NCC}}$ was found to be severely affecting the compressive strength of the normal conventional concrete, see Fig (6).

Table 3. Mechanical properties of hardened concrete

Mix.	Type of concrete	Compressive Strength kg/cm^2	Splitting tensile strength kg/cm^2	Flexural strength kg/ cm^2
$M_{1\text{-HWC}}$	HWC	393	45.27	48.48
$M_{2\text{-HWC}}$		365	38.91	48.63
$M_{3\text{-HWC}}$		342	38.90	51.81
$M_{4\text{-HWC}}$		431	46.33	40.44
$M_{5\text{-HWC}}$		338	39.61	49.68
$M_{6\text{-HWC}}$		418	42.44	46.20
$M_{7\text{-HWC}}$		372	36.10	41.88
$M_{8\text{-HWC}}$		276	33.96	44.40
$M_{1\text{-SCC}}$	SCC	291	44.21	35.16
$M_{2\text{-SCC}}$		319	40.32	47.00
$M_{1\text{-NCC}}$	NCC	213	26.88	41.28
$M_{2\text{-NCC}}$		272	34.66	36.36
$M_{3\text{-NCC}}$		191	33.25	29.40
$M_{4\text{-NCC}}$		154	29.00	22.68

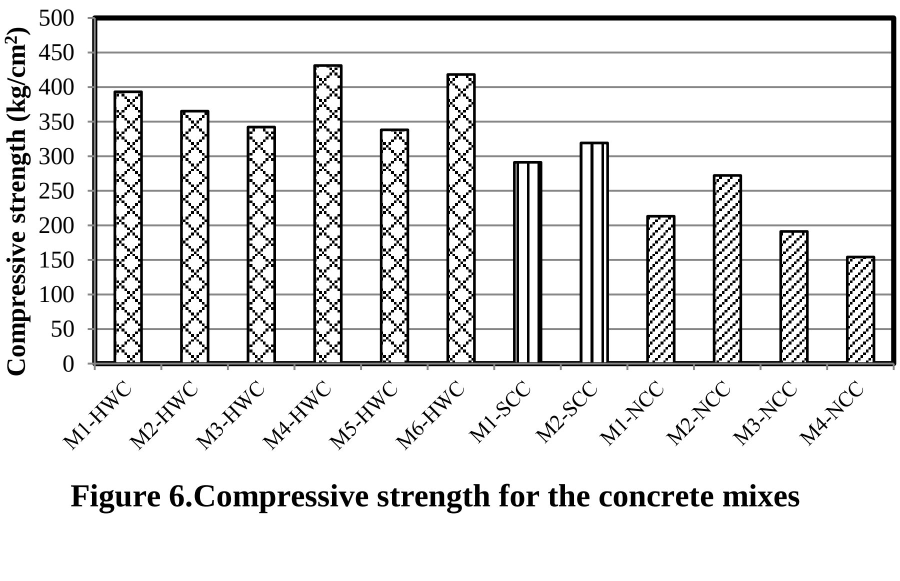

Figure 6.Compressive strength for the concrete mixes

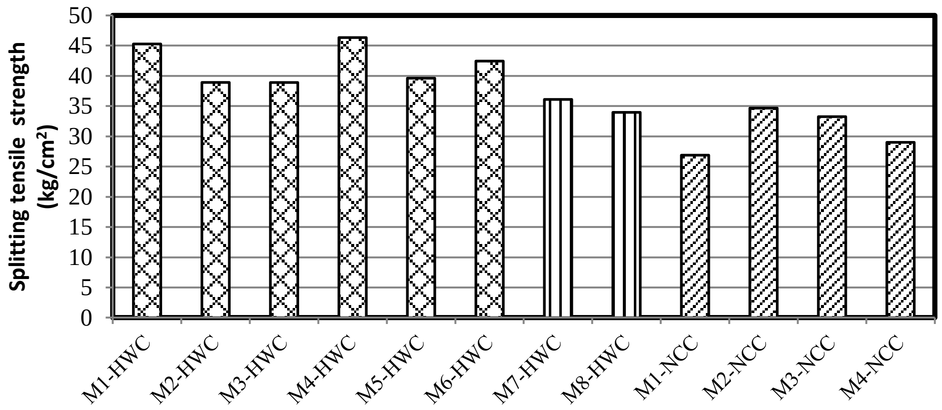

Figure 7.Splitting tensile strength for the concrete mixes

3.2.2 Splitting tensile strength

Table (3) and Fig (7) show the values of the 28-days splitting tensile strength for all concrete mixes. The average splitting tensile strength for the HWC mixes that have cement content of 350 kg/m^3 and 400 kg/m^3 were 35 and 42 kg/cm^2, respectively. Almost similar values of average splitting tensile strength (42 kg/cm^2) were recorded for the HWC and the SCC. The highest values of splitting tensile strength were obtained for mixes contain 5 % silica fume. The average splitting tensile strength of the NCC was 31 kg/cm^2, which is 26% lower than those of the HWC and SCC. The tendency of increasing the values of splitting tensile strength is attributed to the better microstructure of the HWC and the SCC (Cristian, 2003). The use of 0.55 w/c ratio for the production of the NCC mix ($M_{4\text{-NCC}}$) resulted in low splitting tensile strength (29 kg/cm^2).

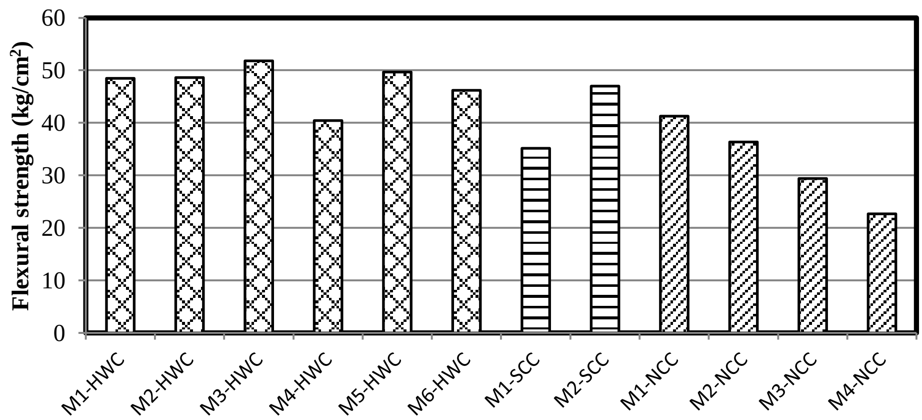

Figure 8. Flexural strength for the concrete mixes

3.2.3 Flexural strength

The flexural strength for the HWC, SCC, and NCC mixes were obtained from testing standard concrete prisms under four point loads, see Table (3) and Fig (8). The average values of the flexural strength for the HWC that have 350 kg/m^3 cement content was 43 kg/cm^2. This value equal 47.5 kg/cm^2 for the HWC mixes contains 400 kg/m^3 cement content. The average flexural strength of the HWC mixes is higher than the average flexural strength of the SCC and the NCC mixes by 10% and 46%, respectively. Similar to the compressive strength and the splitting tensile strength, the use of high w/c ratio for the NCC mixes ($M_{3\text{-}NCC}$ and $M_{4\text{-}NCC}$) resulted in the lowest values of flexural strength, see Fig (8).

4 CONCLUSIONS

Based on the present experimental investigation, the following conclusions can be drawn:

1- The production of highly workable concrete (HWC) can be easily done by optimizing the percentages of the fine to coarse aggregate as well as by using fine powders and super-plasticizer. Because of its high workability, the use of HWC mixes can reduce about 50% of the time and energy required for compaction. The enhanced mechanical properties of the HWC mixes clarifies that the production of HWC is promising and economic.

2- New experimental tests, vibrating L-Box and aggregate segregation, were suggested to check the fresh properties of the highly workable concrete. The experimental test results showed that the HWC mixes have high workability and high resistance to aggregate segregation.

3- The average compressive strength for the highly workable concrete mixes, that have 400 kg/m^3 cement content, was found to be 25% and 80% higher than the average compressive strength of the SCC and NCC mixes, respectively. Increasing the (gravel/sand) ratio and the presence of the silica fume were found to be positively affecting the values of the compressive strength for the HWC.

4- Similar to the compressive strength, the splitting tensile strength and the flexural strength of the highly workable concrete mixes were found to be higher than those of the normal conventional concrete which is attributed the better micro structure and homogeneity of HWC mixes.

5 REFERENCES

Abhishek S. S. and C. Vipulanandan (2004) “Flow properties of self consolidating concrete with time” CIGMAT, Conference & Exhibition.

ASTM C143 / C143M - 12 “Standard Test Method for Slump of Hydraulic-Cement Concrete”.

Cristian D. (2003) “Tensile strength and bonding characteristics of self compacting concrete” Thesis, Louisiana university.

EFNARC (2002) “Specification and Guidelines for Self-Compacting Concrete”.

Egyptian Technical Specifications for Self Compacting Concrete (2007).

Hajime, O. and Masahiro, O. (2003). “Self-compacting concrete” Journal of Advanced Concrete Technology, Vol. (1), No. (1), pp. 5-15.

Klaus H. and Yvette K. (2002) “A Database for the evaluation of hardened properties of SCC” LACER No. 7, pp. 123-134.

Per, J. A. and Simon K. H. (2009). “Highly workable concrete compositions having minimal bleeding and segregation” Patents, http://www.faqs.org/patents/app/20090158960#ixzz2FFm6uGy6