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A Data Base for Self-Compacting Concrete in Iraq

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Abstract

Self-Compacting Concrete is considered one of most remarkable developments in concrete technology. It is a new type of high performance concrete with the ability of flowing under its own weight and without the need of vibrations. Recently, a great native interest had been derived towards self-compacting concrete.

This work aims to present a summary study about properties of fresh self-compacting concrete depending on the results obtained by some native researches, thus focusing on the main common features between their results. It had been focused on the effect of type and proportions of constituent materials incorporated in producing self-compacting concrete. This considered the most influential factors in controlling its properties.

Keywords: Iraqi self-compacting concrete, properties of fresh self-compacting concrete, materials of self-compacting concrete

قاعدة بيانات حول الخرسانة ذاتية الرص في العراق

الخلاصة: -

تعتبر الخرسانة ذاتية الرص واحدة من اكثر التطورات البارزة في تكنولوجيا الخرسانة, وهي صنف جديد من الخرسانة عالية الاداء التي تكون لها القابلية على الانسياب تحت تأثير وزنها الذاتي دون الحاجة الى استخدام الهزازات وقد حظيت باهتمام محلي واسع في السنوات الاخيرة.

يهدف هذا البحث الى تقديم دراسه مختصرة حول خواص الخرسانة ذاتيه الرص بالحالة الطرية وذلك بالاعتماد على ماتوصلت اليه بعض من الابحاث المحليه, وذلك بهدف تسليط الضوء على اهم القواسم المشتركة بين نتائج هؤلاء الباحثين. تم التركيز على تاثير نوع ونسب المواد الداخلة في انتاج الخرسانة ذاتية الرص لاغراض المقارنة بين الخواص الطرية للخلطات المختلفة, حيث تعتبر العوامل الاكثر اهمية في السيطرة على خواص الخرسانه الذاتية الرص.

Nomenclature: -

HRM	Highly Reactive Metakaolin
HRWRA	High Range Water Reducing Admixture
LSP	Limestone Powder

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1. Introduction: -

Self- compacting concrete (SCC) is a relatively new type of concrete that is highly flowable and non-segregating, does not require vibration when cast, is capable of flowing through narrow opening or extremely congested reinforcement, and provides a void-free surface. It is also known as self-consolidating concrete, self-leveling concrete, and high fluidity concrete. (1)

SCC was first developed in Japan about 20 years ago. It had been used in special applications as a solution to concrete's durability concerns. In the early 1990's there was a limited public knowledge about the self-compacting concrete, the fundamental and practical know-how was kept secret by the large corporations to maintain commercial advantage. In the last decade the use of self-compacting concrete spreads worldwide, and just recently a great interest has been derived towards this concept in Iraq.

The objective of this paper is especially focus on the properties of fresh Self- compacting concrete with regards to some M.SC. and PhD. researches that conducted in Iraq and aimed to produce SCC by using available Iraqi materials. Because even with the existing of European guidelines and other international guidelines there are practical differences in how SCC is produced in each country. These differences primarily arise from the difference in cementitous materials available in each region. As example in Europe the ready availability of inert fine fillers such as limestone and dolomite allow the producers to design more economical SCC mixes with higher paste content as compared to their counterparts in Iraq. This difference and others lead to somewhat different design philosophies. However, there are many commonalities in approaching SCC so valuable information can be gained from the international approaches and with some modifications it can be applied to approach SCC with Iraqi materials.

2. Advantages of Self-Compacting Concrete: -

One of the practical advantages of SCC over conventional concrete is its lower viscosity and, thus, its greater flow rate when pumped. As a consequence, the pumping pressure is lower, reducing wear and tear on pumps and the need for cranes to deliver concrete in buckets at the job site (2). This also reduces significantly the construction period and the amount of personal necessary to accomplish the same amount of work. SCC gives designers and contractors a solution for using concrete in special problems, like casting of complicated shapes of elements, heavily congestion of reinforcement, or casting of areas with difficult access. In all these cases, the use of conventional concrete compromises the durability of the structure due to poor consolidation. SCC is also called a "healthy" and "silent" concrete as it does not requires external or internal vibration during and after pouring to achieve proper consolidation. Where the mechanical vibration is a noisy and demanding task for the members of the casting team. The reduction or total elimination of this assignment diminishes the environmental impact as well as the overall cost. (3, 4)

3. Performance of Self-Compacting Concrete: -

The performance of Self-Compacting Concrete should be adequately established so that the performance required of the structure or

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members can be attained and the requirements for the construction can be satisfied, in consideration of various conditions. These conditions include the structural conditions, such as shapes, dimensions and reinforcement layout, methods of transporting, placing, finishing and curing.

SCC is a high-performance concrete with the special property of the fresh concrete “self compacting”. As with other high-performance concretes (e.g. high-strength concrete, acid-resistant concrete) the special properties of these concretes, which differ from conventional concretes are achieved only by systematic optimization both of the individual constituents and of the composition. The flowability and mix stability of the SCC are determined primarily by the interactions between the powder (cement and additions with a particle diameter < 0.125 mm), water and plasticizer. The gradation of the individual size groups in the overall grading curve also affects the property of the concrete of not being blocked by the reinforcement.

4. Properties of Fresh Self-Compacting Concrete: -

In principle, the properties of the fresh self-compacting concretes should not be different from conventional concrete. Only one exception is regarding the consistency. SCC is generally distinguished by their special fresh concrete properties (5). SCC must be evaluated from the rheological point of view, of which SCC is considered as a Bingham plastic fluid with two parameters, the yield value and plastic viscosity. Concrete is a concentrated suspension of solid particles (aggregates) in a viscous liquid (cement paste). Cement paste is not a homogeneous fluid it self composed of particles (cement grains) in a liquid (water). If the viscosity of the mortar is high enough, the coarse aggregate will be supported by the mortar, thus avoiding segregation. While the use of superplasticizer lowers the yield stress, viscosities such as Viscosity Modifying Agent (VMA) or mineral admixtures are added to increase the viscosity of the paste, without significantly increase the yield stress (6).

The workability of SCC is higher than the highest class of consistence described for conventional concrete and can be characterized by the following properties: (1,7,8)

- Filling ability: which is defined as the ability of fresh concrete to flow, maintaining homogeneity whilst undergoing the deformation necessary to completely fill the formwork, encasing the reinforcement and achieving compaction through its own weight.
- Passing ability: which is defined as the ability of fresh concrete to flow through tight openings such as between reinforcing rebar without segregation or blocking.
- Segregation resistance: which is defined as the ability of fresh concrete to remain homogenous in composition during and after placement, without separation of individual components. It is also referred to the concrete stability.

A concrete mix can only be classified as self-compacting concrete if the requirements for all three characteristics are fulfilled. (8)

5. Mix design: -

For the production of SCC, the mix design should be performed so, that the predefined properties of the fresh concrete are reached for sure. The basic components of the mix composition of SCC are the same as those used in conventional concrete. However, to obtain the requested properties of fresh concrete in SCC, a higher proportion of ultrafine materials and the incorporation of chemical admixtures are necessary. (9) The components shall be coordinated one by one so that segregation, bleeding and sedimentation are prevented. [(5)]

A rational mix design process should be used, to reduce the number of trial tests in laboratory. Moreover, a simple trials-and-errors method may lead to too high paste volume in SCC, and then to higher cost and higher delayed strains, which may decrease the durability of the concrete. [(9)]

Many methods have been developed in the recent years for mix design of SCC e.g. EFNARC Approaches [(8)], Okamura and Ozawa method [(10)], CBI^2 method [(11)] and others. A complicated aspect of SCC production is that each mix must be specially designed based on available materials, required performance specifications and production practices.

6. Test Methods: -

Many different test methods have been developed in attempts to characterize the properties of SCC. So far no single method or combination of methods have achieved universal approval and most of them have their adherents. Similarly no single method has been found which characterizes all the relevant workability aspects so each mix design should be tested by more than one test method for the different workability parameters.

For the initial mix design of SCC all three workability parameters (filling ability, passing ability and segregation resistance) need to be assessed to ensure that all aspects are fulfilled. A full-scale test should be used to verify the self-compacting characteristics of the chosen design for a particular application. While for site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are slump-flow and V-funnel or slump-flow and J-ring. [(8)] Table (1) shows alternative test methods for the different parameters.

7. Materials for Self-Compacting Concrete: -

SCC consists of much the same materials as conventional concrete but usually has different admixtures and material proportions. In all cases, material proportions must be developed through trial mixes, which give the opportunity to evaluate the compatibility of the materials and production processes. [(5, 7, 12)]

The effects of SCC components on its fresh properties are summarized below depending on some available Iraqi researches. [(6, 15, 16, 17, 18, 19, 20, 21)]

7.1. Powder Materials: -

Powder materials are included hydraulic cements, supplementary cementitious materials (pozzolanic or latent hydraulic powders) and inert powder (limestone, dolomite, or granite dust finer than 0.150 mm). [(12)]

One of the most common ways of having adequate viscosity of concrete is increasing the content of the powder ingredients, where the high powder content act as "lubricant" for the coarse aggregates as shown in Fig. (1). [(5)]

Kennedy [(13)] in his theory "Excess Paste Theory", confirmed the fact that to attain workability, it is necessary to have not only enough cement paste to cover the surface area of the aggregates, so as to minimize the friction between them, but also more of it to give better flowability and decreasing the segregation risk. However, excessive values of powder materials could make the mixture too viscous and reduce its mobility.

The European federation **(EFNARC)** [(8)] Specified a typical content of powder ranged from (350 kg) to (600 kg) per cubic meter. It has also indicated that the use of cement content more than 500 Kg/m^3 can be dangerous and increase the heat of hydration and shrinkage. While cement content less than 350 Kg/m^3 may only be suitable with the inclusion of other fine filler, such as fly ash, pozzolan, and etc. Those additions can significantly reduce the heat of hydration, shrinkage and cost as well as improve the long-term performance of the concrete. [8]

Local researches didn't edge away these ranges of powder content. But most of them blended cement with mineral admixtures. It is necessary to have powder content not less than 500 kg/m^3 without exaggerating in cement content. The main mineral admixtures used are highly reactivity metakaolin (HRM) and limestone powder (LSP). Figs. (2) and (3) show the effect of different percentage replacement of HRM and LSP by wt. of cement on slump flow and the corresponding percentage replacement of HRWRA by wt. of cement for each replacement. [6, 16, 19]

7.2 Aggregates: -

1. Fine Aggregate: -

The influence of fine aggregates on the fresh properties of the SCC is significantly greater than that of coarse aggregate. All conventional concreting sands are suitable for SCC, both crushed or rounded sands can be used. Gap graded aggregates are frequently better than those continuously graded, which might experience greater internal friction and give reduced flow. On the other hand, it is necessary to use aggregates with continuous grading in order to ensure good spacing between the aggregates. Hence, avoiding segregation. [8]

The local researches suggested the sand content to be ranged from (40 to 53)% by volume of mortar. [6, 15, 16, 17, 19, 20, 21] Figs. (4 to 7) show the effect of different volume contents of sand on different fresh properties of SCC.

2.Coarse Aggregates: -

In principle all types of aggregates are suitable to produce SCC. Lightweight aggregate has been successfully used for SCC, although the aggregate may migrate to the surface if the paste viscosity is low [7]. Hadhrati [18] proved the possibility of incorporating lightweight aggregate (porcelinite rocks) into self-compacting high performance structural concrete as shown in Figs. (8 to 11) where all coarse aggregate are lightweight aggregates. While, (50-100)% of the fine aggregate are replaced by lightweight aggregates.

The maximum size of the coarse aggregates depends on the particular application and is usually limited to 20 mm, however particle sizes up to 40 mm have been used in SCC [8]. Khaleel [16] and Rahim [17] indicated that the flowability of SCC decreases with the increase of the maximum size of coarse aggregate from 10 to 20 mm. Although the mechanical properties of SCC mixes containing 10 mm maximum size of coarse aggregate are higher than mixes with 20 mm maximum size of coarse aggregate.

The particle size distribution and the shape of coarse aggregate directly influence the flow and passing ability of SCC and its paste demand. The more spherical the aggregate particles the less they are likely to cause blocking and the greater the flow because of reduced internal friction. [7] However, crushed aggregates tend to improve the strength because of the interlocking of the angular particles. [8]

Figs. (12, 13, 14) show the effect of size and shape of coarse aggregate on the fresh properties of SCC, those Figs. are excogitated from local researches. [6, 16, 19]

The European Federation **(EFNARC)** [8] Specified a typical volume content of coarse aggregate that ranged from (28 to 35) % by volume of the mix. While many Iraqi researchers exceeded these limits, confirming that the volume content of coarse aggregate could be form up to 42% of the volume of the total mix. [6, 17, 19, 21]

Collepardi et al [14] indicated that the volume and maximum size of the coarse aggregate must be lower than 340 L/m^3 and 25 mm respectively, in order to avoid segregation collision among aggregate particles, which can block the concrete flow.

Rahim [17] studied the influence of volume ratio and size of coarse aggregate on the properties of SCC. Figs (15 to 18) are revealing this effect depending on Rahim's results.

7.3. Chemical Admixtures: -

Chemical admixtures are needed to improve the mobility of the fresh concrete without excess in the volume of water and to reduce the segregation risk without excess in the value of powder volume. Two types of chemical admixtures are commonly used in producing SCC. These are high range water reducing admixtures (superplastizicers), which gives the opportunity to produce SCC that easily reaches a compressive strength of more than 150 Mpa [3]. In Iraq, many types of superplastizicers are used to achieve self-compatibility. For example: Rheobuild SP1 which is a high performance superplasticising admixture based on sulphonated naphthalene polymers, and Structuro 335 which is based on polycarboxylic technology both admixtures are comply with ASTM type F. While the second type of chemical admixtures that is used in SCC industry is viscosity-modifying admixtures, which are generally cellules derivatives, polysaccharides or colloidal suspensions. These products have the same rule as the fine particles: minimizing bleeding and coarse aggregate segregation by thickening the paste and retaining the water in the skeleton. [5, 8, 15]

It is considered more beneficial to apply both admixtures together, or using new generation of admixtures that serves as superplastizicer and viscosity-modifying agent like Glenium 51. Which is based on a unique carboxylic ether polymer with long lateral chains, designed to ensure a good consistency and stability in concrete with very high fluidity. Figs. (19 to 22) show the effect of using different types of chemical admixtures on fresh properties of SCC. [15]

8. Conclusions: -

The conclusions driven from this study are presented below:

1- It has been found that the most important issue in producing self-compacting concrete is the providing of a sufficient amount of powdered materials, thus increasing the viscosity of mortar and thereby decreasing the segregation risk as well as to minimize the friction between the coarse aggregate particles and thereby give better flowability characteristics. It is effective to increase the powdered content by incorporating different mineral admixtures to have powder content not less than 500 Kg/m^3.
2- Increasing the fine aggregate content up to 53% by volume of mortar improves the flowability of self-compacting concrete and decreasing its tendency to segregation.
3- Rounded coarse aggregate with maximum size up to 20 mm found to be the most suitable aggregate to producing self-compacting concrete. However, an acceptable self-compacting concrete had been produced by using crushed coarse aggregate. It has been concluded that is a well-graded coarse aggregate could be account up to 42% of the mixture volume without promising its self-Compactablity.
4- In spite of, the possibility of segregation occurrence when using light weight aggregate due to aggregate migration to the surface when the paste viscosity is low, it had been concluded that is under a precision control conditions, light weight aggregate could be incorporated in self-compacting concrete either as fine aggregate, coarse aggregate or both and with

volume content up to 100% of the total aggregate content.

5- This study supporting the necessity of using chemical admixtures to verify the workability requirements of self- compacting concrete. The more effective chemical admixtures in this field are the high range water reducing admixtures and viscosity modifying admixtures.

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Table (1): Test methods for workability properties of SCC and acceptance criteria [7]

	Method	Property	Unit	Typical range of values	
				Minimum	Maximum
1	Slump-flow by Abrams cone	Filling ability	mm	650	800
2	T50cm slump flow	Filling ability	sec	2	5
3	J-ring	Passing ability	mm	0	10
4	V-funnel	Filling ability	sec	6	12
5	V-funnel at T5 min	Segregation resistance	sec	0	3
6	L-box	Passing ability	H2/H1	0.8	1.0
7	U-box	Passing ability	H2-H1 (mm)	0	30
8	Fill-box	Passing ability	%	90	100
9	GTM screen stability test	Segregation resistance	%	0	15
10	Orimet	Filling ability	sec	0	5

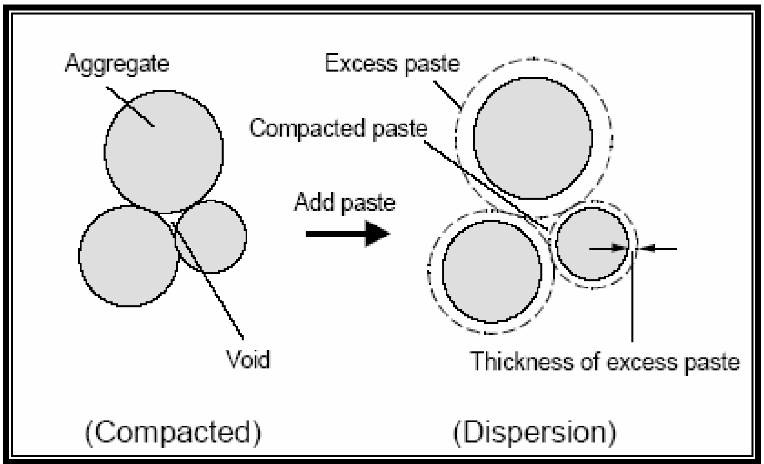

Figure (1): Excess paste theory [13]

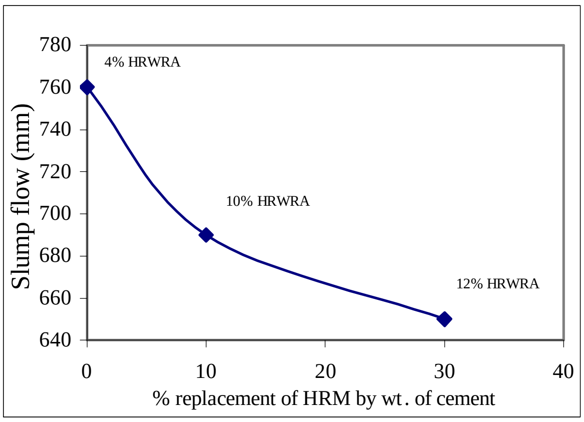

Figure (2): The effect of different % replacement of HRM by wt. of cement on slump flow and the corresponding % replacement of HRWRA by wt. of cement for each replacement.

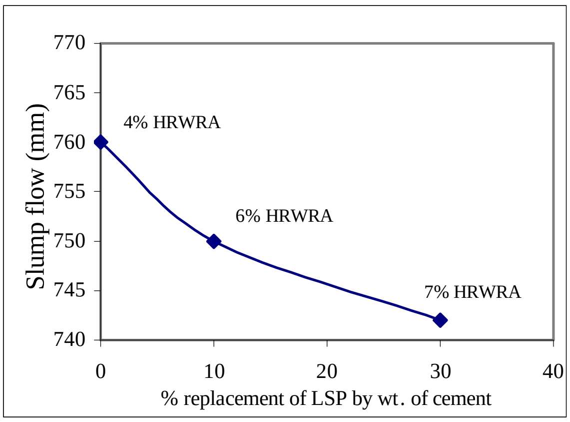

Figure (3): The effect of different % replacement of LSP by wt. of cement on slump flow and the corresponding % replacement of HRWRA by wt. of cement for each replacement.

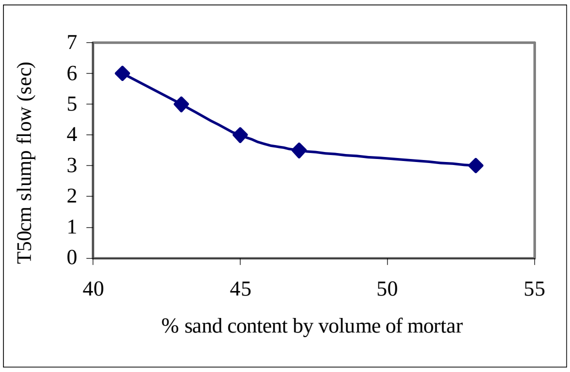

Figure (4): The effect of different volume contents of sand on filling ability of concrete by slump

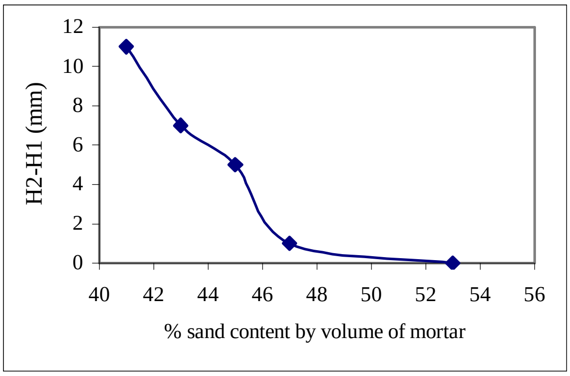

Figure. (5): The effect of different volume contents of sand on passing ability of concrete by U-

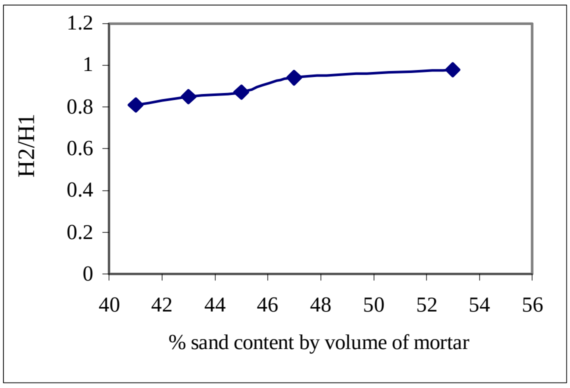

Figure (6): The effect of different volume contents of sand on passing ability of concrete by L-

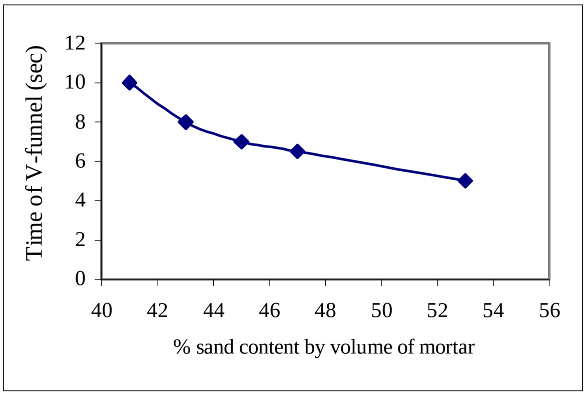

Figure (7): The effect of different volume contents of sand on filling ability of concrete by V-

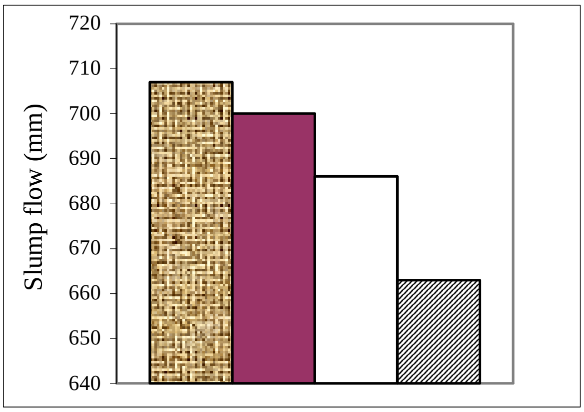

Figure (8) : The effect of using different % replacement of lightweight aggregate on filling ability of concrete by slump flow test

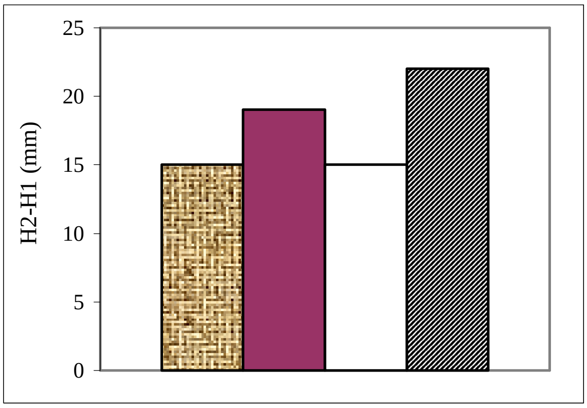

Figure (9) : The effect of using different % replacement of lightweight aggregate on passing ability of concrete by U-box test

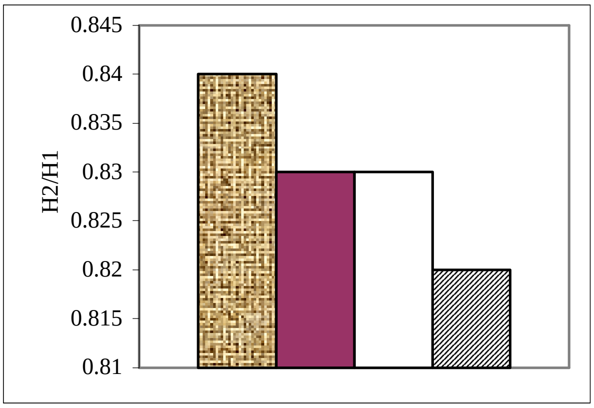

Figure (10) : The effect of using different % replacement of lightweight aggregate on passing ability of concrete by L-box test

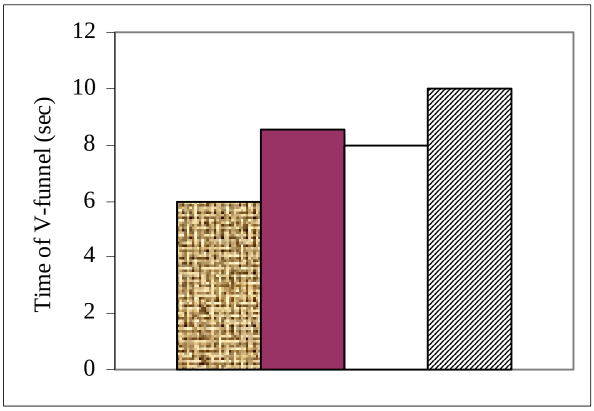

Figure (11): The effect of using different % replacement of lightweight aggregate on filling ability of concrete by V-funnel test

Mix with 100% lightweight fine aggregate.

Mix with 100% lightweight fine aggregate. and 8% of HRM as replacement to the cement

Mix with 100% lightweight fine aggregate

Mix with 100% lightweight fine aggregate and 8% of HRM as replacement to the cement

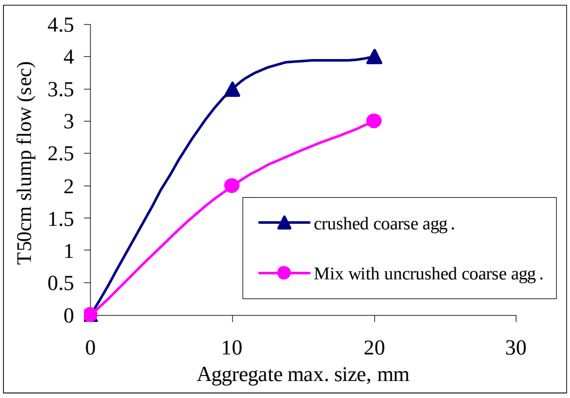

Figure (12) : The effect of size and shape of coarse aggregate on filling ability of concrete by slump flow test

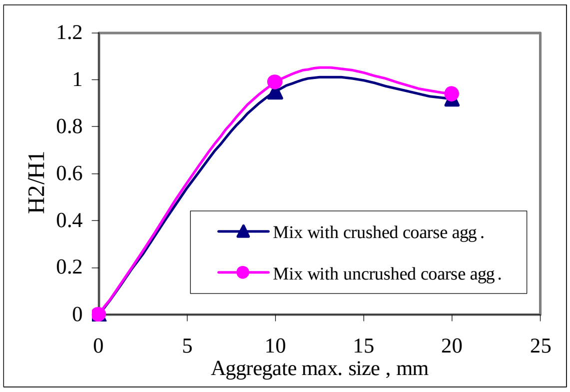

Figure (13) : The effect of size and shape of coarse aggregate on passing ability of concrete by L-box test

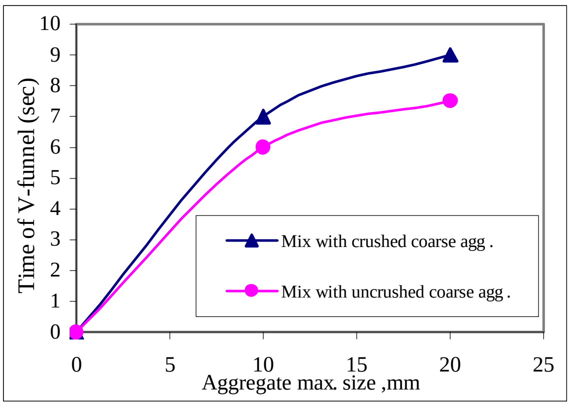

Figure (14) : The effect of size and shape of coarse aggregate on filling ability of concrete by V-funnel test

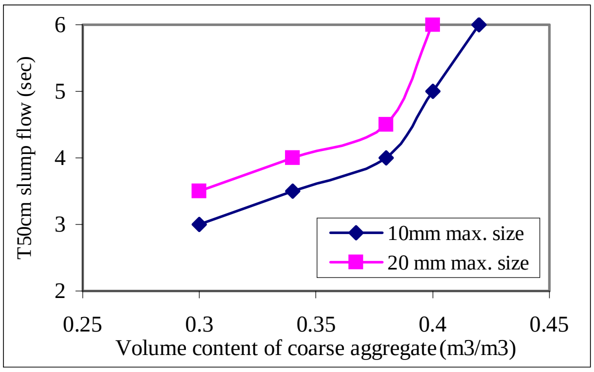

Figure (15): The effect of volume ratio and size of coarse aggregate on filling ability of concrete by slump flow test

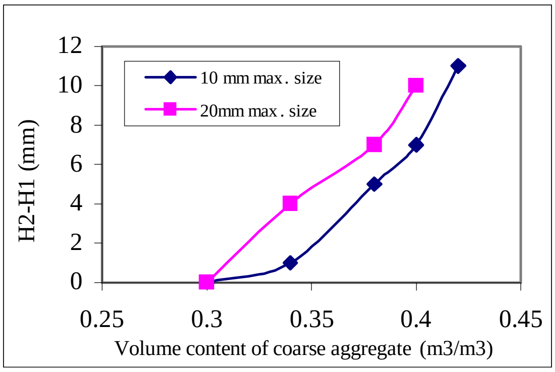

Figure (16) : The effect of volume ratio and size of coarse aggregate on passing ability of concrete by U-box test

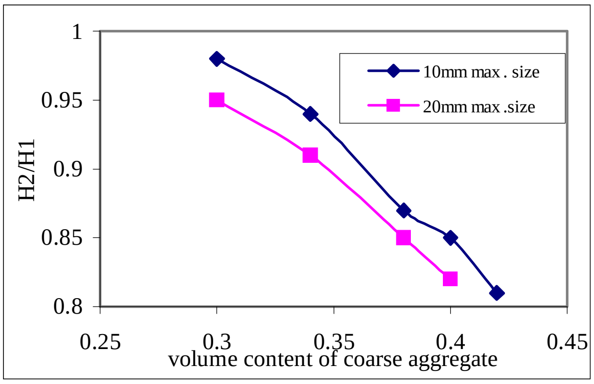

Figure (17) : The effect of volume ratio and size of coarse aggregate on passing ability of concrete by L-box test

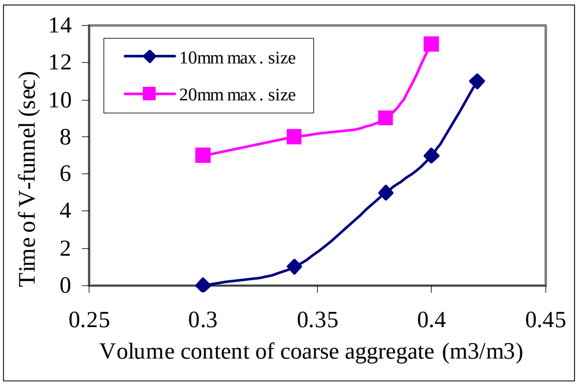

Figure (18) : The effect of volume ratio and size of coarse aggregate on filling ability of concrete by V-funnel test

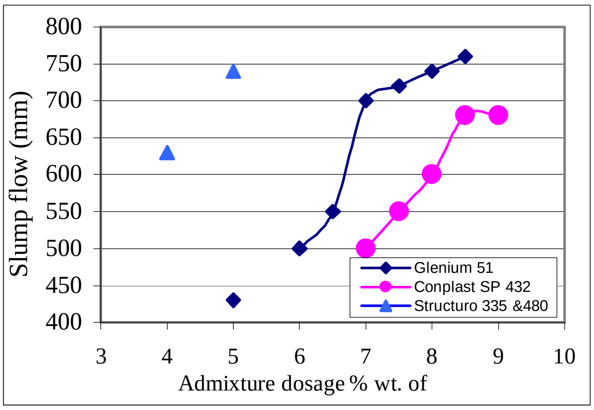

Figure (19) : The effect of using different type of chemical admixtures on filling ability of concrete by slump flow test

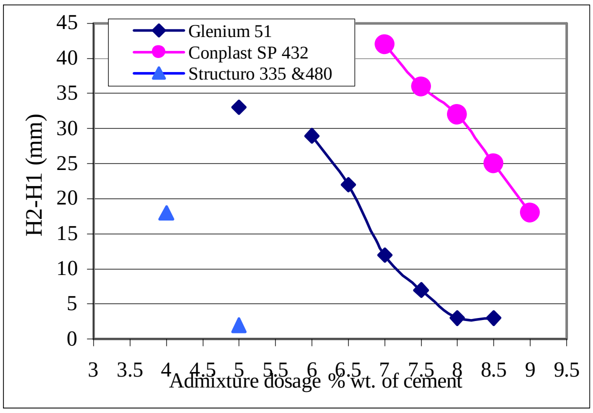

Figure (20) : The effect of using different type of chemical admixtures on passing ability of concrete by U-box test

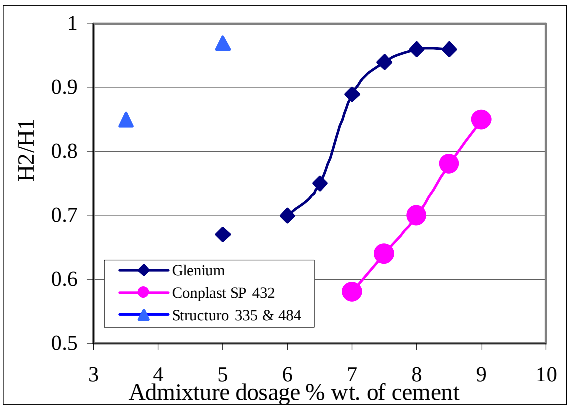

Figure (21) : The effect of using different type of chemical admixtures on passing ability of concrete by L-box test

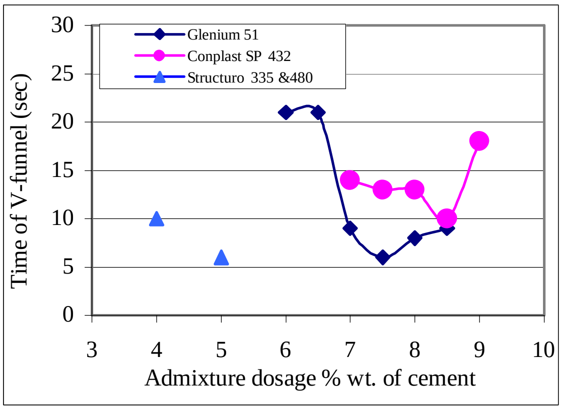

Figure (22) : The effect of using different type of chemical admixtures on filling ability of concrete by V-funnel test