وزارة التعليم العالي والبحث العلمي

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كلية الهندسة

تأثير لهب النار على بعض الخواص الميكانيكية للخرسانة ذاتية الرص باستخدام أنواع مختلفة من المواد المالئة

رسالة تقدم بها الطالب

أحمد طالب عبيد

إلى مجلس كلية الهندسة / قسم الهندسة المدنية

وهى جزء من متطلبات نيل درجة الماجستير – علوم هندسة مدنية

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Effect of Exposure to Fire Flame on Some Mechanical Properties of Self-Compacting Concrete Using Different Types of Filler

College of Engineering

Civil Engineering Department

A Thesis

Submitted to the College of Engineering of the University of Babylon in Fulfillment Of Partially Requirement for The Degree of Master Of Science in Civil Engineering

By ***Ahmed Talib Obeed***

Supervised by ***Assist. Prof .Dr. Ghalib .M. Habeeb***

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٢٠٠٧ May ١٤٢٨ Jmad al-awal

الإهداء

إلى وجهك الكريم مالك الملك.. رب السمـوات السبـع ورب الارضين السبع..

إلى البار الصادق الامين نبينـــا محمــد ﴿صلى الله عليه وال بيته أجمعين ﴾

إلى الوالدين اللذين ربياني صغيراً ، ورعياني كبيراً واللذين أنـــا مدين لـهما بما منَ الله علي من علمٍ ومعرفة ، واللذين لاافك عن الدعاء لـهما عقب كل صلاة .

إلى إخواني الكرام....

احمد

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Ahmed Talib Obeed

٢٠٠٧

بسم الله الرحيم الرحيم

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ {١}خَلَقَ
الْإِنسَانَ مِنْ عَلَقٍ {٢}اقْرَأْ وَرَبُّك
الْأَكْرَمُ {٣}الَّذِي عَلَّمَ بِالْقَلَمِ{٤} عَلَّمَ
الْإِنسَانَ مَا لَمْ يَعْلَمْ {٥}

صدق الله العلي العظيم

سورة العلق

CERTIFICATE

We certify that we have read the thesis titled "***Effect of Exposure to Fire Flame on Some Mechanical Properties of Self-Compacting Concrete Using Different Types of Filler***", was prepared by **"*Ahmed Talib Obeed*** " in its content and in what is connected with it, and that our opining it meets the standard of thesis for the degree of Master of Science in Civil Engineering (***Construction Materials***).

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ABSTRACT

Self –Compacting Concrete (SCC) is a concrete with the ability to compact itself only by means of its own weight without the requirment of vibration.This research is studied the effect of exposure to fire flame on some mechanical properties of SCC using different types filler .

This work is divided into two parts, the first part was to design SCC and to study its workability parameters, and some mechanical properties before heating .Three SCC mixes are used. The first mix, self compacting-concrete content (sand powder)as a filler ; named(MS),the second mix, self compacting-concrete content(limestone powder) as a filler ; named (ML), the third mix self compacting-concrete content(pigment) as a filler ; named (MP). To determine the workability, different test methods are used such as

slump flow, L –box, U-box, and V-funnel. The second part is to investigate its residual mechanical properties after subjecting it to fire flame. The properties investigated were, compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity. Two Non destructive test methods rebound number and Ultrasonic pulse velocity was used to assess the mechanical properties of the SCC.

The values of slump flow are (٧٧٥-٦٧٥)mm, T٥٠cm between (٢-٢.٨) seconds , blocking ratio (H٢/H١) of L-box is between (٠.٩٢-٠.٩٨) , filling height (H٢-H١) of U-box is between (١٠-٢٥)mm, and V-funnel time is between (٧-٩) seconds.

The specimens were subjected to fire flame ranged between (٣٠٠-٦٠٠)C ° at age of ٥٧ days. Three temperature levels of ٣٠٠, ٤٥٠ and ٦٠٠ C° were chosen with three different exposure durations of ٠.٥,١.٠ and ١.٥ hours without any imposed loads during heating .The specimens for each of the temperatures were heated and cooling with air and water.

Based on the results of this work , it is possible to produce self-compacting concrete from available materials which satisfie the requirement of this type of concrete and the filler type (limestone powder) used in self –compacting concrete gives more fire resistance than other types of filler used(sand powder and pigment). The residual percentage compressive strength was ranged between (٦٢-٩٢%)at ٣٠٠ °C ,(٥٦-٨٥%) at ٤٥٠ °C and (٤٢-٦٩%) at ٦٠٠ °C with cooling by air. Cooling by water caused further reduction in the compressive strength, compared with specimens cooled in air , the percentage reduction in compressive strength of the specimens cooled in water was(٣-١١٪).The residual percentage splitting tensile strength was ranged between (٥٠-٨٥%)at ٣٠٠ ^{o} C , (٣٤-٦٩%) at ٤٥٠ ^{o}C and (٢٢-٥٩%)at ٦٠٠ ^{o}C . By cooling in water, the percentage reduction in splitting tensile strength of the specimens was(١-٨٪) compared with specimens cooled in air. The residual percentage flexural strength was ranged between (٤٤-٨٥%) at ٣٠٠ ^{o}C,(٢٦-٧١%) at ٤٥٠ ^{o}C and (١٩-٦٥%)at ٦٠٠ ^{o}C. The residual percentage static modulus of elasticity was ranged between (٥٣-٩٤%)at ٣٠٠ ^{o} C , (٣٠-٨٤%) at ٤٥٠ ^{o}C and (٢٤-٧٥%)at ٦٠٠ ^{o}C.

الخلاصة

توصف الخرسانة ذاتية الرص على أنها خرسانة لها القابلية على رص نفسها تحت تأثير وزنها دون الحاجة إلى متطلبات الاهتزاز. هذا البحث يدرس تأثير لهب النار على بعض الخواص الميكانيكية لخرسانة ذاتية الرص باستخدام أنواع مختلفة من المواد المالئة.

انقسم العمل في هذا البحث إلى قسمين ،الأول هو تصميم خرسانة ذاتية الرص ،ودراسة خواص الخرسانة الطرية والميكانيكية قبل تعرضها إلى لهب النار. استخدم في هذا البحث ثلاث خلطات من خرسانة ذاتية الرص,الخلطة الأولى ,خرسانة ذاتية الرص تحتوي على مادة مسحوق الرمل(sand powder) كمادة مالئة سميت (MS). الخلطة الثانية ,خرسانة ذاتية الرص تحتوي على مادة مسحوق الحجر الجيري (limestone powder) كمادة مالئة ,سميت(ML). الخلطة الثالثة ,خرسانة ذاتية الرص تحتوي على مادة الأصباغ (pigment) كمادة مالئة وسميت (MP).الطرق المختبرية التي استخدمت لإيجاد قابلية التشغيل هي فحص الهطول ,الصندوق على شكل L,الصندوق على شكل حرف U,والقمع على شكل V. إما الجزء الثاني فشمل دراسة خواصها وتأثرها بدرجات الحرارة.الخواص الميكانيكية التي تضمنتها الدراسة شملت ،مقاومة الانضغاط،مقاومة الشد،مقاومة الانثناء ومعامل المرونة . استخدم فحصان غير أتلافين هما فحص الأمواج فوق الصوتية ومطرقة الارتداد لإيجاد بعض الخواص الميكانيكية للخرسانة.

كانت قيم الانسياب تتراوح بين(٦٧٥-٧٧٥)ملم ومقدار الوقت لانسياب الخرسانة بعد اجتياز قطر (٥٠) سم يتراوح (٢-٢.٨)ثانية ,نسبة الانسداد للصندوق بشكل حرف L كانت تتراوح بين (٠.٩٨-٠.٩٢),كما ان فرق الارتفاع لملء الصندوق بشكل حرف U كان يتراوح بين (١٠-٢٥)ملم والزمن اللازم لاجتياز بوابة الصندوق بشكل حرف V يتراوح بين (٧- ٩) ثانية.

عرضت النماذج الخرسانية إلى درجات حرارة تراوحت بين (٣٠٠-٦٠٠ م°) ،بثلاث مستويات من الحرارة ٣٠٠,٤٥٠ و٦٠٠ م ° ، وبثلاث مديات تعرض هي ٠.٥,١ و ١.٥ ساعة وبدون تسليط اى حمل إثناء التسخين .جميع النماذج سخنت وبردت بنوعين من التبريد (بالهواء وبالماء) للمقارنة بين النوعين.

أظهرت نتائج هذا البحث انه يمكن أنتاج خرسانة ذاتية الرص من المواد المحلية المكونة لهذا النوع الخرسانة وان المادة المالئة من نوع مسحوق الحجر الجيري المضافة للخرسانة ذاتية الرص تُحسن من مقاومة الحريق أفضل من المواد المالئة الأخرى,مسحوق الرمل والأصباغ, وان الخرسانة ذاتية الرص حساسة إلى درجات حرارة . مقاومة الانضغاط المتبقية لنماذج المبردة بالهواء تتراوح بين (٩٢- ٦٢%) عند ٣٠٠ م°،

(٥٦-٨٥%) عند ٤٥٠ م°, (٤٢-٦٩%) عند ٦٠٠ م °,وحصل نقصان اكبر في مقاومة الانضغاط نتيجة تبريدها بالماء مقارنة مع نماذج الخرسانة المبردة بالهواء ,كانت النسبة في الانخفاض هي(٣%-١١).

مقاومة الشد المتبقية لنماذج المبردة بالهواء تتراوح بين (٥٠-٨٥%) عند ٣٠٠ م° ، (٦٩- ٣٤%)عند ٤٥٠ م°, (٢٢-٥٩%) عند ٦٠٠ م° ,أما النقصان في مقاومة الشد نتيجة تبريدها بالماء فكانت نسبته تتراوح بين(١%-٨) مقارنة مع نماذج الخرسانة المبردة بالهواء.

مقاومة الانثناء المتبقية لنماذج المبردة بالهواء تتراوح بين (٤٤-٨٥%) عند ٣٠٠ م°، (٢٦-٧١%)عند ٤٥٠ م°, (١٩-٦٥%) عند ٦٠٠ م° , أما معامل المرونة الساكن المتبقي تتراوح بين (٥٣-٩٤%) عند ٣٠٠ م° (٣٠-٨٤%)عند ٤٥٠ م°, (٢٤-٧٥%) عند ٦٠٠ م° .

CERTIFICATE

We certify that the thesis titled "***Effect of Exposure to Fire Flame on Some Mechanical Properties of Self-Compacting Concrete Using Different Types of Filler***", was prepared by "***Ahmed Talib Obeed al-Janabei*** ", under our Supervision at Babylon University in Fulfillment of Partial Requirements for the Degree of Master of Science in Civil Engineering.

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Chapter One

Introduction

١- ١ General

The term self-compacting concrete (SCC) refers to a "new" special type of concrete mixture, characterized by high resistance to segregation that can be cast without compaction or vibration[١].

The concept of self-compaction concrete (SCC) results from research into underwater concrete, in situ concrete piling and the filling of other in accessible areas. Before the advents of superplasticizer and other admixtures, the cost of mixes for these purposes is often expensive with high cement contents required to offset associated high water concrete. The development of water -reducing super-plasticizer means that high-workability and high -strength could be achieved without excessive cement contents, but excessive segregation and bleeding restrict the use of admixtures to flowing concrete [٢].

With regard to its compaction, SCC consists of the same components as conventionally vibrated normal concrete, which are cement, aggregates, water, additives and admixtures. However, the high amount of super-plasticizer for reduction of the liquid limit and for better workability, the high powder content, as well as the use of viscosity agents to increase the viscosity of concrete are factors to be taken into account [٣]. In principle, the properties of the fresh and hardened self-compacting concrete, which depend on the mix design, should not be different from the properties of normally vibrated concrete. One exception is only the consistency. Figure (١-١) shows the basic principles for the production of SCC.

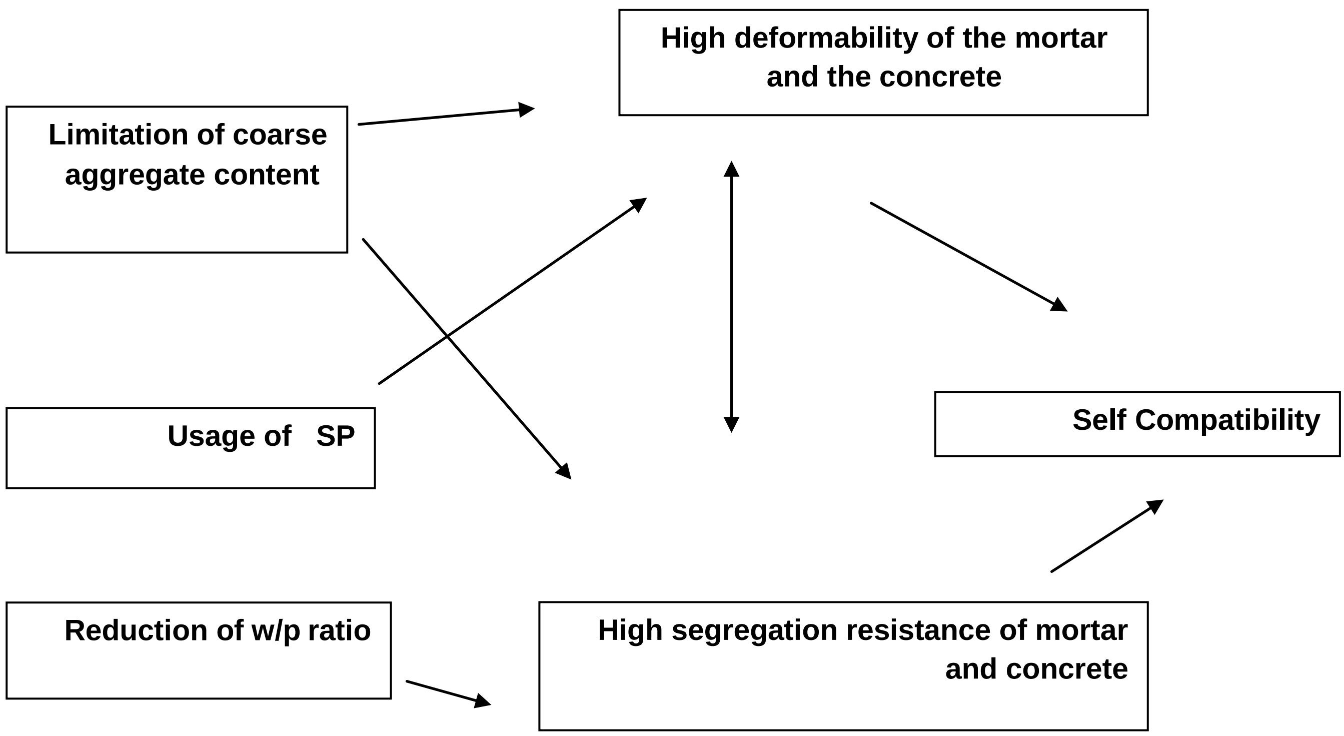


Figure (١-١): Basic principles of SCC [٢].

Insufficient compaction will lead to the inclusion of voids, which does not only lead to a reduction in compressive strength but strongly influences the natural physical and chemical protection of embedded steel reinforcement afforded by concrete. The consequences of concrete compaction do not only affect the material but also have health, safety, environmental risks and high levels of noise, "full compaction" does not actually produce a homogeneous concrete (Wallevik and Nielsson, ١٩٨٨) cited by Johan N. et al[٢].

The majority of concrete casting relies on compaction to ensure that adequate strength and durability are achieved. Concrete is normally compacted manually using vibrators. It is often operated by untrained lab our and the supervision of the process is inherently difficult. Although poorly compacted concrete can be repaired, overall durability is more than not reduced .

This type of concrete needs more advanced mix design than traditional vibrated concrete and more careful quality assurance with more testing and checking. SCC must have a great filling ability through dense reinforcement and a high segregation resistance during and after placing the concrete [٢].

Japan has used SCC in bridge, building and funnel constructions since the early of ١٩٩٠. In the last five years, a number of SCC bridges have been constructed in Europe. In the United States, the applications of SCC in high way bridge construction are very limited at this time. However, the U.S pre-cast concrete industry is beginning to apply the technology to architectural concrete. SCC has high potential for wider structural applications in high way bridges [٤].

Further benefits of SCC are [٥].

١. Self-leveling, fill all voids, no segregation, easy to deliver and its materials are available.
٢. High performance, durability and workability.
٣. Improve surface finish and design flexibility.
٤. Reduced labor costs, equipment on job site, safety, shorten construction time and reduced over all in-place costs.

١- ٢ Research Significance

In this work it is aimed to produce ***self-compacting concrete*** (SCC) from the available materials and studying the effect of exposure to fire flame on some mechanical properties of SCC using different types of filler,such as compressive strength ,splitting tensile strength, flexural strength and modulus of elasticity. Since production of this type of concrete is limited, and, need to be investigated ,particularly when it is used in special structures ,which may be designed to endure elevated temperatures or fire flame.

Information about SCC before and after subjected to fire flame is still rare and contradictory, so a full-fledged investigation of its residual mechanical properties is necessary.

١- ٣ Objective and Scope

This work is performed to produce self-compacting concrete characterized to be extremely soft and fluid concrete. Concrete strength ranging between (٢٢-٤٢ MPa) and investigates the influence of filler type with the concrete mixes to enhance their mechanical properties. The destructive tests (compressive, splitting , flexural and modulus of elasticity tests) and two non- destructive tests ,(the ultrasonic pulse velocity and rebound hammer) were conducted .

The SCC specimens were subjected to fire flame temperatures ranged between (٣٠٠-٦٠٠°C) ,with three period of exposure (٠.٥,١.٠ and ١.٥ hour), the mechanical properties were measured. The previous concise description of self-compacting concrete behavior makes it possible to introduce the objectives of this work, which attempts to:

١- Design Self-compacting concrete according to the requirement of the fresh and mechanical properties of concrete.

٢- Evaluate the effect of filler types on workability, compressive strength, splitting tensile strength and flexural strength of SCC.

٣- Investigate the effect of exposure to fire flame on some mechanical properties of SCC using different types of filler.

٤-Use non-destructive methods to evaluate and predict the dynamic mechanical properties of SCC.

١- ٤ Thesis Layout

This research consists of four other chapters:-

Chapter (**two**) is concerned with literature review on SCC. Chapter (**three**) will go over the properties of the materials used ,the procedure adopted and the tests carried out throughout the experimental work,

The results of the experimental work have been presented and discussed in chapter (**four**). The conclusions and a number of suggested commendations for further researches have been mentioned in chapter (**five**).

Chapter Two

Review of Literatures

٢-l Introduction

Compacting Concrete (SCC) is" defined so that no additional inner or **–** ***Self*** s ' outer vibration is necessary for compaction. It is compacting itself due to it self-weight and is de-aerated almost completely while flowing in the formwork. In structural members with high percentage of reinforcement it fills a nearly has and ”also completely all voids and gaps. SCC flows like “HONEY placing [١]. after level concrete horizontal

SCC can produce much higher fluidity with no occurrence of segregation, due to its lower yield value and higher viscosity than conventional concrete. However, the fresh property of SCC cannot be evaluated by conventional consistency tests such as slump test. It must be evaluated from the rheologyical point of view, of which SCC is considered as a Bingham plastic fluid with two parameters, the yield value and plastic viscosity[٢].Two basic categories of concrete are considered: a 'housing' category (normal strength) and a 'civil engineering' category (high strength) with characteristic cube strengths of ٣٥ MPa and ٧٥ MPa respectively[٢].

The use of SCC is spreading world wide because of its very attractive properties in fresh state as well as after hardening .The use of SCC leads to a more industrialized production ,reduce the technical costs of in situ cast concrete constructions ,improvement the quality ,durability and reliability of concrete structures and elimination some of the potential for human error .It will replace manual compaction of fresh concrete with a modern semi-automatic placing technology and in that way improve health and safety on and around the construction site [٦] .

٢- ٢ Effect Of The Mix Components On Properties Of SCC

Ralf and Sika [٣] recommended that each material, cement, sand aggregate, coarse aggregate, concrete admixture, filler, and pozzolans for (SCC) must be evaluated according to type, strength characteristics, gradation, fineness, and interaction in combination with each other.

Self-compacting concrete material selection and mix proportioning are more process than the design of housing and civil engineering mixes. To achieve high workability and avoid obstruction by closely spaced reinforcing, SCC is designed with limits on the nominal maximum size (NMS) of the aggregate, the amount of aggregate, aggregate grading, high fine to coarse aggregate ratio, a low water- cementations material ratio (w/p), and high -range water- reducing admixture [٧].

٢- ٢- ١Cement

The first choice to be made when making SCC is definitely that of the cement, even when one or two supplementary cementations materials are used, because the performance of cement in terms of the rehology and strength becomes a curial issue as the targeted workability and compressive strength increase [١] .

Okmura H. ١٩٩٨[٨]. pioneering work in Japan , focused primarily on using (PC) for SCC. In developing SCC, the total fines content of the mix is balanced against aggregate size and grading and ,in general, the fines content is much higher than in conventional concrete for reasons of stability .The requirement for a high fines content leads to high cement content , often in the rang ٤٥٠-٥٠٠ $Kg/m^{٣}$. The typical content of cement in the mix is (٣٥٠-٤٥٠ $Kg/m^{٣}$) . Cement content more than ٥٠٠ $Kg/m^{٣}$ can be dangerous and increase the shrinkage, while the content less than ٣٥٠ $Kg/m^{٣}$ may only be suitable with the inclusion of other fine filler, such as fly ash, pozzolan, etc. When cement content of C٣A is higher than ١٠٪ it may cause problems of poor workability retention

***Jianxin M.* et. al.** [٩] found that when replacing ٣٠ % of cement by quartz powder, the slump flow increased from ٥١٠ mm to ٦٢٠ mm and because of high binder content, (٩٥٠ $Kg/ m^{٣}$ of cement + filler) and low water to powder ratio, concrete shows a higher autogenously shrinkage than conventional concrete.

The direct effect of cement on concrete could be simplified by the fact that the cement paste is the effective part in the concrete and the strength of mortar or concrete depends on the cohesion of the paste and its adhesion to the aggregate particles. Variations in chemical composition and physical properties of the cement affect SCC compressive strength more than variations in any other single material [١٠].

٢- ٢ - ٢ Aggregate

٢- ٢- ٢- ١ Coarse Aggregate

Coarse aggregate properties affect aggregate-cement bond characteristics and mixing water requirements. Generally, good quality aggregate must be used, to ensure good bond between the coarse aggregate particles and the matrix. SCC has been made with both gravels and crushed rock as coarse aggregate. The nominal maximum size is generally (٥-٢٠) mm. Regarding the characteristic of different types of aggregate, crushed aggregates tend to improve the strength because of the interlocking of the angular particles. Whilst rounded aggregates improve the flow because of lower internal friction[١١].

When the volume of coarse aggregate in concrete exceeds certain limits, the opportunity for collision or contact between coarse aggregate particles increases rapidly and there is an increase in risk of blockage when the concrete passes through spaces between steel bars [١٢].

The optimum coarse aggregate content depends on the following parameters:-

١. Maximum aggregate size. The lower the maximum aggregate size, due to the higher operation of coarse aggregate.
٢. Crushed or round aggregate. For round aggregate a higher content can be used than for crushed aggregate.

٢-٢-٢-٢ Fine Aggregate

Fine aggregate in SCC plays a major role in the workability and stability of the mix. The total fines content of the mix is a function of filler content and fine aggregate content with the grading of the fine aggregate is particularly important. The grading of fine aggregate in the mortar should be such that both workability and stability are simultaneously maintained(٧).

Many researches have been done to optimize the fine aggregate characteristics for SCC. ***Dirch H.*** **et. al** [١٣] studied the effect of type different sands on workability of SCC; five natural and five artificial form sand were used , each pair having identical grading curves but different particle shape and surface texture. They found that increasing the fineness of sand particles leads to increasing yield stress and plastic viscosity and increasing the ratio (fine/total) leads to increasing yield stress and plastic viscosity . The influence of changing particle shape and surface texture by replacement of the artificial sand with the natural sands is not as easy to observes the artificial and natural sands to some extent also vary with regard to fineness .

Su K. **et al** [١٤] studied the effect of (fine aggregate volume / total aggregate volume {F/T})on modulus of elasticity of self-compacting concrete. Slump flow test and U-box test were tested to evaluate concrete flow ability. They used different (F/T) ratio concretes which were cast and tested then the modulus of elasticity of SCC was compared with the modulus of elasticity of normal concrete. They found that the flow ability of SCC increases with the increase in (F/T). However, the modulus of elasticity of SCC is not significantly affected by (F/T) when total aggregate volume was kept constant .

٣-٢-٢ Admixtures

Super-plasticizers are essential components of the SCC to provide the necessary workability. Other types of admixtures may be incorporated as necessary, such as viscosity modifying agents (VMA) for stability, air entraining admixtures (AEA) to improve freeze-thaw resistance, retreads for control of setting, etc. V.M.A. admixtures are not specially covered in EN ٩٣٤-٢; ٢٠٠٠, like other admixtures do, but should conform to the general requirements in the standard of test methods of SCC[١١].

Orjan P. [١٥] concluded that the use of higher admixture contents to increase the blocking ratio and the use of viscosity agent increases the viscosity and makes the concrete more cohesive with fewer risks for separation.

Super-plasticizer (S.P.) has been used in Japan since the late ١٩٦٠s and much of the development of super-plasticizer concrete has occurred there where super-plasticizers have been used to reduce water content by as much as ٢٠ to ٣٣٪ compared with ١٠ to ١٥٪ using normal water reducing admixtures. Super-plasticizers can be used in three ways [١٦] :

١- To produce high strength concrete by reducing water demand.
٢- To reduce cement content while maintaining water cement ratio and workability.
٣- To maintain water and cement content with greatly increased workability "flowing concrete .

Today, new developments of admixtures based on the polycarboxylate technology give an extremely strong plasticizing effect, allow very high water reduction to keep the concrete stable and homogenous, with some specially designed products based on much improved chemistry. The polycarboxlate technology had been used in Europe since ١٩٩٠s, the water reduction is up to ٤٠٪, the mode of action is satiric hindrance and ionic repulsion [١٦]. It can been seen in Table (٢-١) [٤] .

Table (٢-١) shows the admixture development.[٤]

Type of Super plasticizers	Year	% water reduce
plasticizers	١٩٦٠	١٠-١٥
Poly-Super-plasticizers	١٩٧٠	٢٠-٣٣
Poly modified Super-plasticizers	١٩٨٠	٣٠-٣٥
Carboxylic ethers	١٩٩٩	UP to ٤٠

٢- ٢- ٤ *Filler Material*

The use of the so-called "Supplementary cementations material or fillers" has become a more common practice so that many modern concretes now incorporate fly ashes, slag natural, pozzolans, silica fumes, limestone fillers, silica fillers or rice husk ash, etc. These finely divided materials can be part of a blended cement or simply be added to the concrete at the batching plant[١٧].

Finely divided inorganic material [١٨]used in concrete in order to improve certain properties or to achieve special properties. There are two types of addition:

١- Nearly inert additions (Type I).

٢- Pozzolanic or latent hydraulic additions (Type II).

The following additions are covered:

* fly ash (Type II).

* ground granulated blast furnace slag (ggbs) (Type II).

* metakaolin (Type II).

* silica fume (Type II).

* limestone fines (Type I).

* pigments (Type I).

Fillers are commonly used in SCC due to the need for substantial contents of fine particles. All additions conforming to EN standards are suitable .Due to the special rheological requirements of SCC , both inert and reactive additions are commonly used to improve and to maintain the workability, as well as to regulate the cement content and so reduce the heat of hydration [١٨].

٣- ٢- ٤- ١ Limestone Fines

Limestone fines conform to BS ٧٩٧٩, Specification for limestone fines for use with Portland cement is a fine powder obtained from the processing of limestone. Its should be classified as a Type I addition. The fraction less than ٠.١٢٥ mm will be of most benefit. The usage of limestone filler in the mix increases the ٢٤ hours compressive strength of concrete [١٨].

٣- ٢- ٤- ٢ Pigments

The specification of the pigments is according to BS EN ١٢٨٧٨. Pigments for the coloration of building material based on cement and lime- specification and method of test are substances. It used as a filling material is to improve the properties of concrete [١٨].

٣- ٢- ٤- ٣ Filler Aggregate

Filler aggregate conforming to BSEN ١٢٦٢٠, aggregates for concrete including those used in roads and pavements are currently in the course of preparation. This standard is expected to "filler aggregate" that is sufficiently at less ٧٥٪ to pass sieve ٠.٠٦٣mm. In this case, a natural sand material of particles less than ٠.٠٧٥mm is used as filler [١٨].

٢-٣ Mix Design

In the mix design of conventional concrete, water/ cement ratio is fixed first, from the view point of obtaining the required strength . With self-compacting concrete, water/ powder ratio has to be decided taking into account self-compatibility because of the sensitivity to this ratio. In most cases, the required strength does not govern the water/cement ratio because the water/ powder ratio is small enough to obtain the required strength for ordinary structures unless most of the powder materials in use are not reactive. Mortar or paste in self-compacting concrete requires high viscosity as well as high deformability which can be achieved by the employment of a super-plasticizer[٤].

٢-٣-١ Mix Design Methods

There are many different mix design theories, but they all mainly separate SCC into two phase design ,namely , "continuous" which covers the water , admixture , cement and fillers with particle size less than ٠.١ mm and "particle" which considers the coarse and fine aggregate [٧]. Some of these theories are summarized below:

٢-٣-١-١ Rational Mix Design Method [٤]

compatibility of – The method was based on the fact that "self concrete can be affected by the characteristics of materials and mix proportions " .

The principle of the mix design method is that " the coarse and compatibility of the – fine aggregate content is fixed so that the self fresh concrete can be achieved by adjusting only the water/powder binder ratio and superplsticize" . The fundamental steps in the procedure are as follows:

Step ١ : The coarse aggregate content is fixed at ٥٠٪ of the solid volume of the concrete.

Step ٢: The fine aggregate content is fixed at ٤٠٪ of the mortar volume.

Step ٣ :The (water /powder) ratio is assumed to be (٠.٩-١.٠٪ by volume)depending on the properties of the binder.

Step ٤ : The super plasticizer dosage and final (water/powder)ratio are determined so as to ensure self- compatibility.

٢-٣-١-٢ Linear Optimization Mix Proportioning (٤)

The optimization mix design method is based on the rational mix design method , but modifies this by using the mathematical approach of linear optimization to produce an optimum mixture of water , powder and aggregate .The mix design procedure is as follows:

Step ١ : A typical air content is chosen (١-١.٥٪ for non-air-entrained mixes)

Step ٢ : The coarse aggregate content is fixed (٠.٥* dry rodded unit weight).

Step ٣: A binder composition is chosen .

Step ٤ : The maximum water /powder ratio is chosen to ensure that the following three experience:

١. The paste has sufficient plastic viscosity (before addition of super-plasticizer) to provide adequate segregation resistance.

٢. The concrete has sufficient compressive strength.

٣. The durability requirements are met.

The minimum value of water /powder ratio from ١ ,٢ and ٣ chosen.

Step ٥ : The volume of the sand in the mortar is chosen.

Step ٦: The paste content is calculated and adjusted if outside the limits.

Step ٧: The water and binder contents are calculated with the water being a limiting factor and set before step ٥ if greater than ٢٠٠ $Kg/m^{٣}$.

Step ٨: The super-plasticizer dosage is then estimated from tests on the mortar component of the mix using the V-funnel test.

Step ٩: The concrete mix is then made and tested for fresh concrete.

٢ - ٣- ٢ Requirements in The Mix Design

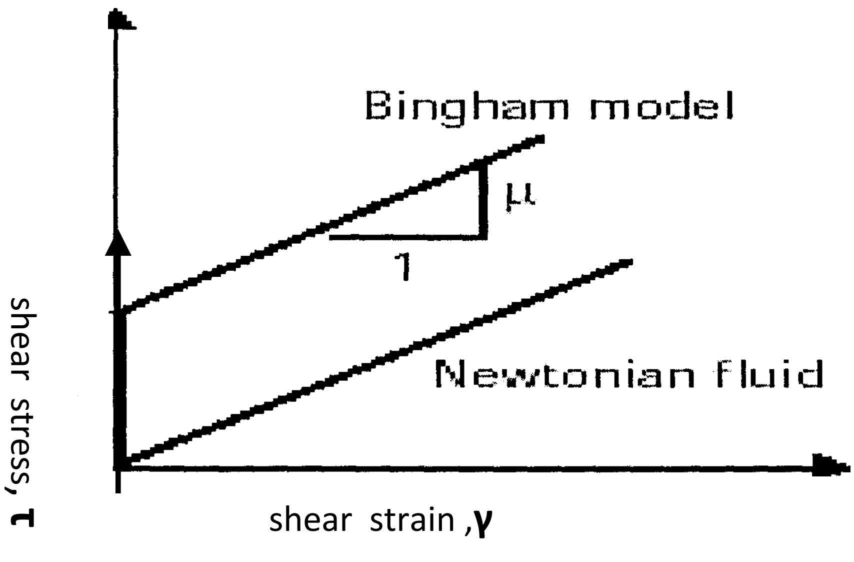
١- A high volume of paste: SCC contains a high volume of paste (cement + additions+ efficient water + air), typically ٣٣٠ to ٤٠٠ L/m^{٣}, the role of which is to maintain aggregate separation the friction between the aggregates limits the spreading and the filling ability of SCC [٦].

٢- A high volume of fine particles (<٨٠ µm): in order to ensure sufficient workability while limiting the risk of segregation or bleeding, SCC contains a large amount of fine particles (around ٥٠٠ kg/m^{٣}). Nevertheless, in order to avoid excessive heat generation, the Portland cement is generally partially replaced by mineral admixtures like limestone filler or fly ash (cement should not be used as a filler) [٦].

٣- A high dosage of super-plasticizer: super-plasticizer are introduced in SCC to obtain the fluidity. Nevertheless, a high dosage near the saturation amount can increase the proneness of the concrete to segregate [٦].

٢- ٤ The Rheologyical Properties of Self-compacting Concrete

Rheology " is the science of the deformation and flow of matter, and the emphasis on flow means that it is concerned with the relationships between stress, strain and rate time". Workability is defined either qualifiedly as the ease of placement or quantitatively by rheologyical parameters [١٩] .The rheology of fresh concrete is described by the Bingham model. According to Fig (٢-١). this model



Figure(٢-١) Bingham Rheology model [١٩].

Fresh concrete must overcome a limiting stress (yield stress, $\tau.$) before it can flow. Once the concrete starts to flow, shear stress increases linearly with increases in strain rate as defined by plastic viscosity, μ Thus, one target of rheological property of SCC is to reduce the yield stress to as low as possible so as to behave like a Newtonian fluid with zero yield stress. The other target property is 'adequate' viscosity [٢٠] . The Bingham equation is a linear-relationship between the strain rate (γ) , and shear stress ($\tau.$) - The viscosity (µ) , is the slope, and the intercept is the yield stress, as shown in the equation below[٢١]:-

$$\tau = \tau_{٠} + \mu \gamma \qquad (٢\text{-}١)$$

Fluidity or deformability means the ability of the flowing concrete to fill every corner of the mould as well ability to pass through small openings or gaps between reinforcing bars, often referred to as filling ability and pass ability of SCC respectively [١٩].

٢- ٤- ١ *Effect of Water and Super plasticizer on Bingham Rheology model*

٢- ٤- ١- ١ *Effect of Water*

The addition of water reduces both the yield stress and viscosity. However, too much water can reduce the viscosity to such an extent that segregation occurs. As mentioned earlier, segregation resistance between water and solid particles can be increased by increasing the viscosity of water through the incorporation of viscosity admixtures [٢٠].

٢- ٤- ١- ٢ *Effect of Super- plasticizer*

The incorporation of S.P. reduces the yield stress and cause reduction in viscosity. The effect of SP on Bingham constants is demonstrated by the results presented in Table (٢-٢) .The water to powder ratio of these pastes was maintained at ٠.٣٦ with various combinations of Portland cement and filler. It can be seen that when the dosage of SP increase the yield stress and plastic viscosity decrease [٢٠].

Table (٢-٢) Bingham constants for paste with w/p of ٠.٣٦ [٢٠].

Powder(%)		Super-plasticizer (%)	Yield stress (Pa)	Plastic viscosity (Pa.s)
cement	limestone			
٦٥	٣٥	٠.١٠	٣٣.٤	٠.٢٦
		٠.٢٠	١٠.٨	٠.٢١
		٠.٣٠	١.٤	٠.١٧
٥٥	٤٥	٠.١٠	٢٣.٣	٠.٢٢
		٠.٢٠	١٠.٢	٠.٢١
		٠.٣٠	٤.٣	٠.١٩
٤٥	٥٥	٠.١٠	١٢.٨	٠.٢
		٠.١٥	٦.٣	٠.١٨
		٠.٢٠	٢.٦	٠.١٦

٢- ٥ *The Workability Tests For SCC*

Many different test methods have been developed in an attempt to characterize the properties of SCC. So far, no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly no single method has been found which characterizes all the relevant workability as facts so each mix design should be tested by more than one test method for the different workability parameters. Alternative test methods for the different parameters are listed in Table (٢-٣) below [٢٢].

Table (٢-٣) Alternative test methods for the different parameters [٢٢]

No.	Method	Property
١	Slump-flow by Abrams cone	Filling ability
٢	T٥٠ cm slump flow	Filling ability
٣	J-ring	Passing ability
٤	U-runnel	Filling ability
٥	V- funnel at T٥ minutes	Segregation resistance
٦	L- box	Passing ability
٧	U-box	Passing ability

٢- ٥-l Slump Flow Test

This test which is easy to carry out, can provide an indication of filling ability, "Filling ability" this property of the fresh concrete is related entirely to the mobility of the concrete. Concrete is required to change shape under its own weight and mould it self into the formwork in place.

Slump flow and T٥٠ values should be different for different maximum sizes/shapes of aggregates and a difficult to assess the segregation/settlement tendency[٢٢].

The test method is based on the test method for "determining the slump. The diameter of the concrete circle is measured for the filling ability of the concrete and the time for the concrete diameter to reach (٥٠٠mm)(T٥٠) is measured.

Two people are needed if the T٥٠ time is to be measured. It can be used on site, though the size of the base plate is some what unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability [٦].

Gettu and Ravenna[٢٣] found that no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. The higher the slump flow (SF) value is the greater its ability to fill form work under its own weight. A value of test ٦٥٠mm is required for SCC. The T٥٠ time is a secondary indication of flow. A lower time indicates greater flow ability. The researcher [٢٢] suggested that a time of (٣-٧) seconds is acceptable for civil engineering applications, and ٢-٥ seconds for housing applications.

٢-٥-٢ L- Box Test

This test, based on a Japanese design for under water concrete. The test assesses the flow of the concrete and blocking by reinforcement .

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC.

"Passing ability", is the ability of concrete to pass round immovable objects in the formwork, such as reinforcement. The need for this ability depends on the reinforcement arrangement. Factors to be considered are the space between reinforcement, which will influence the selection of the size and shape of the coarse aggregate and the volume of the mortar paste. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section [٢٢] .

٣-٥-٢ ***V-Funnel Test***

The test was developed in Japan, and used the equipment consists of a V-shaped funnel, An alternative type of V-funnel, the V-funnel ,with a circular section was also used in Japan[٦] .

The V-funnel test is used to determine the flow ability of the concrete with a maximum aggregate size of ٢٠ mm. The result is affected by concrete properties other than flow. On the other hand, high flow time can be associated with low deformability due to a high paste viscosity with high inter-particle friction [٢٢] .

٢- ٥- ٤ *U-Box Test*

The test was developed by the Technology Research center of the Taisei box-“Group (Hayakawa ١٩٩٣) in Japan .Sometimes the apparatus is called a test. The test is used to measure the filling ability of self-compacting ”shaped concrete.

In this test, the degree of compatibility can be indicated by the height that concrete reaches after flowing through an obstacle .

The box-test is more suitable for detecting concrete with higher possibility of segregation between coarse aggregate and mortar. The equipment consists of U-box [٢٢] .

٢- ٦ *Workability Criteria for Fresh SCC*

The requirements which are to be fulfilled at the time of placing likely changes in workability during transport should be taken into account in production. Typical acceptance criteria for SCC with a maximum aggregate size up to (٢٠)mm are shown in Table (٢-٤).

	Method	Unit	Typical range of values

No			Minimum	Maximum
١	Slump flow Abrams cone	mm	٦٥٠	٨٠٠
٢	T (٥٠cm) slump flow	sec	٢	٥
٣	V-funnel	sec	٦	١٢
٤	L -box	(H٢/H١)	٠.٨	١.٠
٥	U -box	(H٢-H١)mm	٠	٣٠
٦	GTM Screen stability test	%	٠	١٥

Table(٢-٤)Acceptance criteria for SCC [٦].

٢- ٧ Mechanical Properties of SCC:

٢- ٧- ١ Compressive Strength of SCC

It is well known that the properties of concrete are affected by cementations matrix, aggregate, and the transition zone between these two phases. Reducing the water to cement ratio and the addition of pozzolanic admixtures like silica fume are often used to modify the microstructure of the matrix and to optimize the transition zone. The reducing of the water to cement ratio results in a decrease in porosity and reinforcement of capillary pores in matrix [٢٣].Due to the low water / powder ratios associated with SCC, the compressive strength of SCC is usually higher than for conventional concrete. If SCC has been well designed and produced, it will be homogeneous, mobile resistant to segregation and ability to be placed into formwork without the need for compaction . This will encourage minimal interfacial zones to develop between the coarse aggregate and the mortar phase. Thus, the microstructure of SCC is expected to be improved promoting strength , permeability , durability and , ultimately , a longer service life of the concrete [٢٤]. In high performance concrete, water to cement ratio ranges usually between (٠.٢٨-٠.٣٨), while in ultra-high performance concrete the water to cement ratio is even lower than (٠.٢) [٢٥].

For conventional concrete, the proportion between cube and cylinder is ١.٢٥. This relation is essentially lower for SCC and the ratio (fc, cube (١٥٠mm)/fc, cylinder. (١٥٠ x ٣٠٠mm)) is in the range of (١.٠ to ١.١). Consequently, the compressive strength is less related to the slenderness of the specimens[٢٦].

Altan **et. al** [٢٧] studied the **c**ompressive strength of SCC mixes with different fillers and (HRWR).Table (٢-٥) show the high early compressive strength of the SCC .

Table (٢-٥) Compressive strength results of standard specimens at (٢٨ days) [٢٧]

Concrete Mixes		average of compressive strength at٢٨ days, MPa
Housing , Mixes	*SCCH	٤٧.٠
	*RCH	٣٧.٠
	*SCCC	٧٩.٥

Civil Engineering Mixes	*RC	٦١.٥
Fiber SCC Mix	*FSCC	٦٣.٠

*SCCH: Self –compacting concrete housing engineering

* RCH : Reference housing concrete engineering

*SCCC: Self –compacting concrete civil engineering

* RC : Reference concrete engineering

Frank D. et **al** [٢٨] studied the effect of filler type on mechincal properties of SCC. The specimens cubes (١٥٠)mm and (١٥٠*٣٠٠) mm cylinders) were cured in water for ٢٨ days to avoid changing in curing conditions. They found that the high early compressive strength and the high splitting tensile strength of the SCC were due to the use of fly ash. Such concrete types normally have slower strength development because of the lower hydration rate of the fly ash. Therefore, it is difficult to compare the compressive strength with conventional concrete aged ٢٨ days .

Mohammed K. [٢٩],studied the influence of water/binder ratio and type of filler on mechanical properties of SCC.Two type , housing (normal strength (٣٥MPa)) and engineering (high strength (٧٥ MPa)) were designed of SCC.Five type (metakaolin, limeston, cement, pigment, and sand)were used as afiller in SCC.He found that self-compacting concrete (SCC) produced was very sensitive to water/powde ratio ,maximum size of aggregate , type of filler and super-plasticizers dosages. Also he found that early age compressive strength for housing and engineering concrete were (١١-٢٨ MPa) at (٢٤) hours.

۲- ۷- ۲ Splitting Tensile Strength of SCC

The tensile strength was assessed indirectly by the splitting test on cylinders. For SCC, both the tensile strengths themselves, and the relationships between tensile and compressive strengths were of a similar order to those of traditional vibrated concrete [۳۰].

Sonebi.M. **et. al.** [۲] investigated the relation for splitting tensile strength and the compressive strength, The experimental results are shown in Table (۲-٦), which gives the splitting tensile strengths at ۲۸ days and ٦ months.

Table (۲-٦) splitting tensile strength (MPa) [٦]

Results	*RH	*SCCC
Age of ۲۸-d	۲.٤	٤.۷
Age of l۸۰-d	۳.۱	٥.۷
۲۸-d Tensile /Compressive Strength Ratio, %	٦.٥	٥.۰
۱۸۰-d Tensile / Compressive Strength Ratio, %	۷.۷	٦.۲

***RH**: Reference housing concrete engineering

*__SCCC__: Self –compacting concrete civil engineering

۲- ۷- ۳ Flexural Strength of SCC

Tensile strength is usually calculated using indirect measurement, such as the measurement of the flexural strength (modulus of rupture MOR) ASTM C۷۸, ۱۹۹۹.Performing the (MOR) measurement does not present any special difficulties in the case of SCC, so that the same set-ups and procedures used for usual concrete can also be used for SCC[٤].

Malhotra [٣١] found that the flexural strength of mixes studied varies from ٦ to ٨.٧ MPa. The beams were moist cured and then tested in flexure according to BS ١٨٨١;part ١١٨, which provides for a similar test procedure, except that the standard specimens dimensions were (١٥٠*١٥٠*٧٥٠) mm. The theoretical maximum tensile strength or modulus of rupture was then calculated from the simple beam bending formula:

$$R = \frac{pl}{bd^2} ---------(2-2)$$

Where:

R=modulus of rupture,N/mm٢ p= the maximum total load indicated, N L= clear span length, mm b= the specimen width ,mm

d= the specimen depth, mm

This equation is valid only if failure line is within the middle third of span. If failure line is outside mid-third of span by not more than ٥ % of the span length, the equation below is used [٢٦]:

$$R = \frac{3pa}{bd^2} ----------(2-3)$$

Where:

a=the average distance between the point of fracture and the nearest support.

٢-٧-٤ *Modulus of Elasticity*

The modulus of elasticity(***Ec***) of concrete is one of the most important mechanical properties of concrete. The measurement of the elastic modulus of SCC can be done in a similar way as for normal concrete[٣٢]. Static modulus of elasticity is determined as the slope of the secant to the stress- strain in compression, within the elastic zone of the material. Dynamic modulus of elasticity is higher than secant modulus of elasticity[٣٣] **.**

Mohammed K. [٢٩] found that, static modulus of elasticity for concrete mixes containing limestone as a filler was higher than that of cement, fine sand and pigment by (١,١١,١٠.٢) % and (١.٢, ٦.٢, ٥) % for housing concrete at ages ٢٨ and ٩٠ days respectively, while (Ec) of concrete mixes containing metakaolin as a filler was higher than that of limestone, cement, fine sand and pigment by (٠.٣, ٠.٩,٤.٥,٣.٦) % and (٠.٨,٠.٦,٥.٥,٥.٥) % for civil concrete mixes at ages ٢٨ and ٩٠ days respectively . The values of modulus of elasticity at age of ٢٨ days range from (٣٣.٣-٣٧.٣) GPa and (٣٦.٩-٣٨.٨) GPa for housing and civil engineering concrete respectively, while the values of (Ec) at age of ٩٠ days ranged from (٣٥.٨-٣٨.٢) GPa and (٣٧.٦-٣٩.٩) GPa for housing and civil engineering concrete respectively as shown in Figures (٢-٢) and (٢-٣).

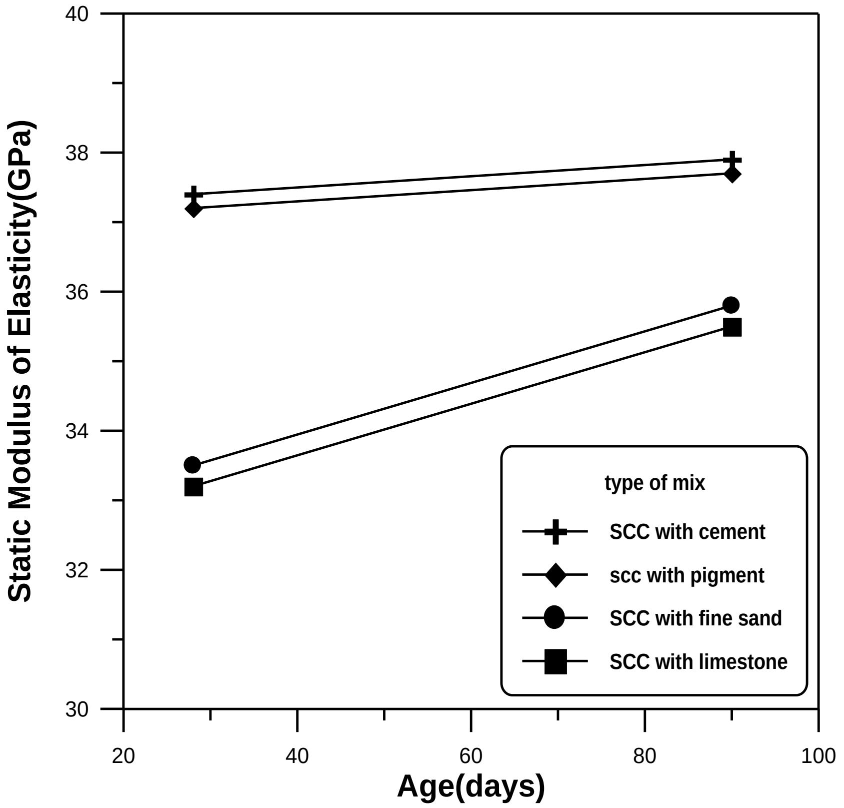


Figure (٢-٢): Relationship between static modulus of elasticity and age of housing concrete [٢٩].

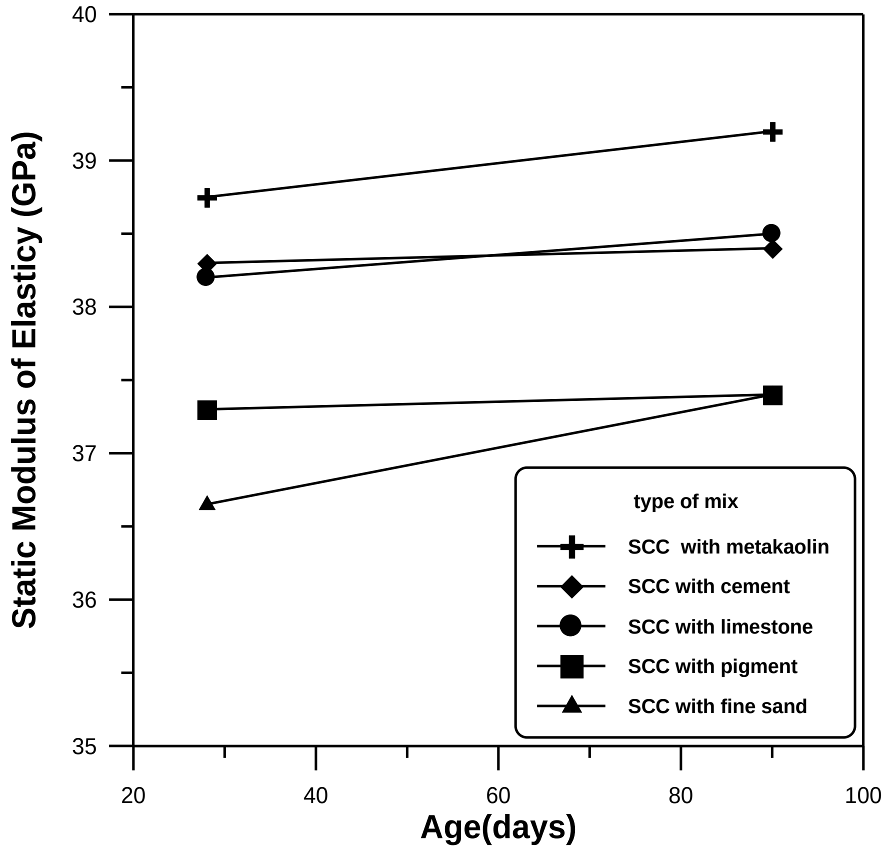


Figure (٢-٣): Relationship between static modulus of elasticity and age for civil engineering concrete [٢٩].

٢-٨ *The Effect of Heating on Concrete*

The concrete construction could be exposed to the effect of fire. Human safety is one of the considerations in the design of residential , public and industrial buildings. On the contrary of steel , when subjected to temperatures below (٧٠٠-٨٠٠°C) , concrete is able to retain an adequate strength for reasonably long period ,thus permitting rescue operations by reducing the risk of structural collapse [٣٤].

Many studies have been carried out to investigate the effect of high temperature on concrete. Some of these investigations, which tended to evaluate the effect of exposure of concrete to high temperatures are discussed below .Other investigations studied the effect of fire exposure on mechanical properties of concrete. The type of aggregate and moisture content play important roles in the manner that concrete is affected. However, size and shape of aggregate, type of cement, admixture and water-cement ratio also influence the results during heating[٣٥].

٢-٨-١ Effect of High Temperatures on concrete

Carette **et. al** [٣٦] studied the effect of high temperatures on concrete made with three types of cement (Ordinary Portland cement, Ordinary Portland cement and slag, and Ordinary Portland cement and fly ash). Cylinders (١٠٢*٢٠٣)mm were cast and stored in normal room temperature. For each type of concrete, compressive and splitting tensile strengths were determined after ٢٨ days of moist curing. The exposure temperatures were ٧٥, ١٥٠, ٣٠٠,٤٥٠ and ٦٠٠ °C. The periods of exposure were ١, ٤, and ٨hrs.

They found that:

١. The compressive and splitting tensile strengths decreased with the increase of temperature up to ٧٥ °C. Their decrease was ١٠٪ with respect to the reference concrete strengths. At ١٥٠, ٣٠٠,٤٥٠ and ٦٠٠°C, the reduction in strengths was (١٠-٢٠٪), (٢٤-٣٩٪), (٣٨-٥٩٪) and (٥٠-٧٥٪) respectively.

٢. The incorporation of fly ash and slag in the concrete did not improve the mechanical properties of concrete after exposure to sustained high temperatures.

Valiasis et al [٣٧] studied the effect of high temperature on the mechanical properties of concrete in which Portland cement concrete cylinder specimens (١٥٠*٣٠٠) mm were used. After ٢٨ days of curing and ٦ months of drying. The specimens were exposed to four temperature levels, ٢٠٠, ٤٠٠, ٦٠٠ and ٨٠٠°C without any imposed load. Groups of three specimens each were crushed at ١ day, ٧days and ٣months after heating. The included variables were compressive strength.

They found that:

١. At ٢٠٠ °C ,the concrete with Portland cement only had a reduction in compressive strength about ٢٥٪. While the concrete with pozzolanic material showed a reduction of ٥٠٪.

٢. At temperature over ٤٠٠°C all tested concrete suffered deterioration and lost ٧٠-٨٠٪ of their initial compressive strength.

Malhotra [٣١] investigated the effect of high temperatures on compressive strength of concrete . The cylinders of (٥١)mm in diameter and (١٠٢)mm long with ages(١٥, ٢٩) days and temperature range (٤٠٠-٧٠٠ °C) were used. Three mixes of aggregate / cement ratios (٣, ٤.٥, ٦) and four water- cement ratios (٠.٤٠, ٠.٤٥, ٠.٥٠, ٠.٦٥) with ordinary Portland cement, river sand and gravel aggregate were used . The specimens were divided into three groups, The first group was tested in the hot state, the second group was tested under a constant stress, and the third group was allowed to cool gradually and tested to find the residual strength after cooling .

He found that :

١. The effect of temperature on compressive strength of concrete is independent of the water-cement ratio within the range of (٠.٤-٠.٦٥).
٢. The reduction in the compressive strength for lean mixes is smaller than for rich mixes.
٣. The concrete under a compressive stress of the order of its design stresses has a smaller proportional decrease in strength than if the stress was absent .
٤. The residual strength of heated concrete shows still further reduction in strength on cooling, being approximately ٢٠٪ less than the corresponding hot strength in temperature range ٢٠٠ to ٤٥٠°C for(cement /aggregate) ratio (١:٤.٥) and(١:٦)concrete mix.

Nasser and Marzauk [٣٨] studied the effect of high temperatures on properties of mass concrete containing fly ash. Concrete cylinders (٧.٥*٢٣.٥)mm were tests. A ٢٥٪ replacement of cement by fly ash was used. The specimens were heated at five different temperatures of (٧١, ١٢١, ١٤٩, ١٧٥ and ٢٣٢ °C). At each temperature minimum of three specimens were tested after being exposed for (٣, ٧, ١٤, ٢٨, ٥٦, ٩١ and ١٨٠)days. After ٢٨ days of moist curing, the specimens were transferred to an electric oven in which they were heated. All specimens were then gradually cooled and tested at the room temperature.

They found that:

١. The increase in the strength and modulus of elasticity after ٦ months of exposure at (٧١ °C) was about ٢٠٪ of those at ٢٨ days.
٢. The compressive strength was reduced to(٢٧ -٥٣٪) after exposure to temperatures of (٢٣٢- ١٧٥°C) for ٦ months respectively

٣. The modulus of elasticity was reduced to(٢٥ -٤٣٪) after exposure to temperatures of (٢٣٢- ١٧٥°C) for ٦ months respectively.

٢-٨-٢ The Effect of High Temperatures on Aggregate

The type and mineralogy of aggregate have important influence on the behavior of concrete to fire. Concrete made with Siliceous or limestone aggregate shows a change in color with temperature , as this is dependant on the presence of certain compounds of iron , there is some difference in the response of different concretes .The change in color is permanent , so that the maximum temperature during a fire can be estimated a posterior; the color sequence is approximately as follows: pink or red between (٣٠٠ and ٦٠٠ °C) , then grey up to about ٩٠٠ °C, and buff above ٩٠٠ °C .Thus the residual strength can be approximately judged[٣٩] .

Siliceous aggregate containing quartz can cause distress in concrete at a bout (٥٧٣ °C) because the transformation of quartz from α to ***β*** form is associated with sudden expansion of the order of ٠.٨٥٪.Carbonate aggregate similar distress can begin above (٧٠٠ °C) as result of the decarbonizes reactive, In addition to , differential thermal expansion between aggregate and cement paste it causes thermal decomposition of concrete [٤٠] .

Abrams [٤١] studied the effect of high temperatures on the compressive strength of concrete by using (٧.٥*١٥)mm cylindrical specimens heated for short duration to temperature of (٩٣-٨٧١°C) . The test specimens were heated without load then tested hot, heated with load and tested hot, and tested cool after heating. The original strength of concrete was (٢٣-٤٥.٥) MPa. Three aggregate types (carbonate, siliceous and lightweight) were used .

He found that:

١. Carbonate aggregate concrete and lightweight aggregate concrete retained about ٧٥٪ of their original strength at a temperature up to ٦٤٩°C when heated without load and tested hot, while the corresponding temperature for the siliceous aggregate concrete was about ٤٢٧°C .

٢. The test procedure has a significant effect, where the strength of the specimens stressed in compression during heating, was generally higher than the specimens that were not stressed during heating. Moreover, the unstressed residual strength (specimens heated, cooled and tested) were lower than the strength of the companion hot tested specimens..

٢-٨-٣Effect of High Temperature onSome Mechanical Properties of Concrete

Al-Ausi and Faiyadh[٤٢] studied the effect of high temperatures and cooling in air and in water on the compressive strength . The concrete mix was ١: ٢: ٤, w/c ratio were (٠.٤, ٠.٤٥, and ٠.٥), the specimens were heated to different levels of temperature up to ٧٠٠ °C for different periods of exposure. Specimens cubes were tested hot, others were tested after cooling in the air and the third group was tested after cooling in the water for two hours. Figure (٢-٤) shows the compressive strength for different types of cooling.

They found that:

١. The compressive strength was not affected significantly after heating to ١٠٠ °C, but the compressive strength decreased about(٦٨-٧٠٪)from the original strength at ٧٠٠°C .

٢. They found that there was an increase in the compressive strength of air- cooled specimens, which were heated to ٢٠٠ °C when compared with hot tested specimens. This finding was not agreed with that obtained by ***Molhatra*** [٣١] , who use a rich mixes(١:١.٥:٣) and get a redaction in compressive strength by about (٢٠٪) less than the hot specimens .

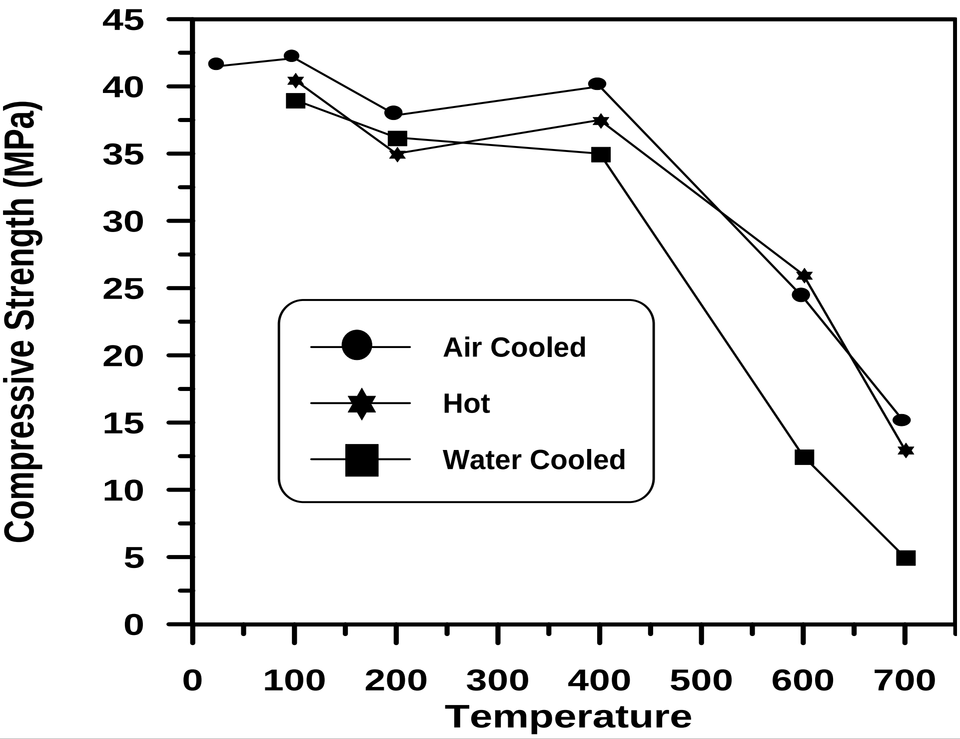


Figure (٢-٤): Relation between temperature and compressive strength, of w/c =٠.٤٥ mix heated for ٩٠ minutes [٤٢]

Umran M. K . [٤٣] studied the effect of fire flame on some mechanical properties of concrete .Two concrete mixes (١:١.٦:٣.٢) with (w/c) (٠.٥٢) and (١:١.٢:٢.٧) with w/c (٠.٤٥) were used with compressive strength ranged from (٣٠ and ٤٠ MPa) .The properties investigated were density , compressive strength , splitting tensile strength , flexural strength and modulus of elasticity .Two non-destructive tests, the ultrasonic pulse velocity and rebound hammer were used. The specimens were subjected to fire flame temperatures ranging from (٤٠٠-٧٠٠ °C) at different ages of ٣٠ , ٦٠ and ٩٠ days .Three temperature levels of ٤٠٠ °C, ٥٠٠ °C and ٧٠٠ °C were chosen with four different exposure duration of ٠.٥,١.٠,١.٥ and ٢.٠ hours.

<u>He found that:</u>

١. The properties of concrete were very sensitive to fire flame and they deteriorated , when the fire flame intensity increased for all ages and periods of exposure .

٢. The residual compressive strength ranged between (٧٠ -٨٥٪) at ٤٠٠ °C ,(٥٩ -٧٨ %) at ٥٠٠ °C and (٤٣ -٦٢ %) at ٧٠٠ °C. Cooling by water caused further reduction in the compressive strength , compared with specimens cooled in air , the percentage reduction in compressive strength of the specimens cooled in water was (٢-٨٪) more than the specimens cooled in air .

٣. The residual tensile strength was (٦٧ -٧٨٪) at ٤٠٠°C, (٤٠ -٦٧٪) at ٥٠٠ °C and (٢٠ ٤٥٪) at ٧٠٠ °C. But the reduction in splitting tensile strength for specimens cooled in water showed more reduction than specimens cooled in air by (٣-١٤٪).

٤. The residual flexural strength was in the range of (٧١ -٧٩٪), (٤٢ -٥٨٪) and (٢٢-٤١٪) for ٤٠٠ °C,٥٠٠ °C and ٧٠٠ °C fire flame temperature.

٥. The residual modulus of elasticity ranged between (٥٥- ٧٥٪), (٣٤-٥١٪) and (١٦-٣٤٪) for ٤٠٠°C,٥٠٠°C, and٧٠٠ °C fire flame temperature, respectively.

Mohamedbhai [٤٤] studied the effect of different periods of exposure and rates of heating and cooling on the residual compressive strength of concrete. The test specimens were(١٠٠)mm cubes. The concrete mix was consisted of ordinary Portend cement (OPC) with mix proportion (١:٢:٤) and (٠.٧) (w/c) ratio were used. The temperature levels (٢٠٠,٤٠٠ ,٦٠٠ and ٨٠٠ °C) with four exposure times (١,٢,٣ and ٤ hours) were used .Two type of heating and cooling (slow and quick).

<u>He found that</u>

The residual compressive strength of concrete was about (٨٠ ,٧٠ ,٦٠ ,and ٣٠٪)of their unheated strength for temperatures (٢٠٠,٤٠٠,٦٠٠ and ٨٠٠ °C) respectively, after(١hour)of their unheated strength. The corresponding residual strengths after two hours of exposure were about (٧٠, ٦٠, ٤٥ and ٢٥٪).The rates of heating and cooling had no effect on the residual strength of concrete heated to ٦٠٠ °C. This can be seen from Figures (٢-٥) and (٢-٦).

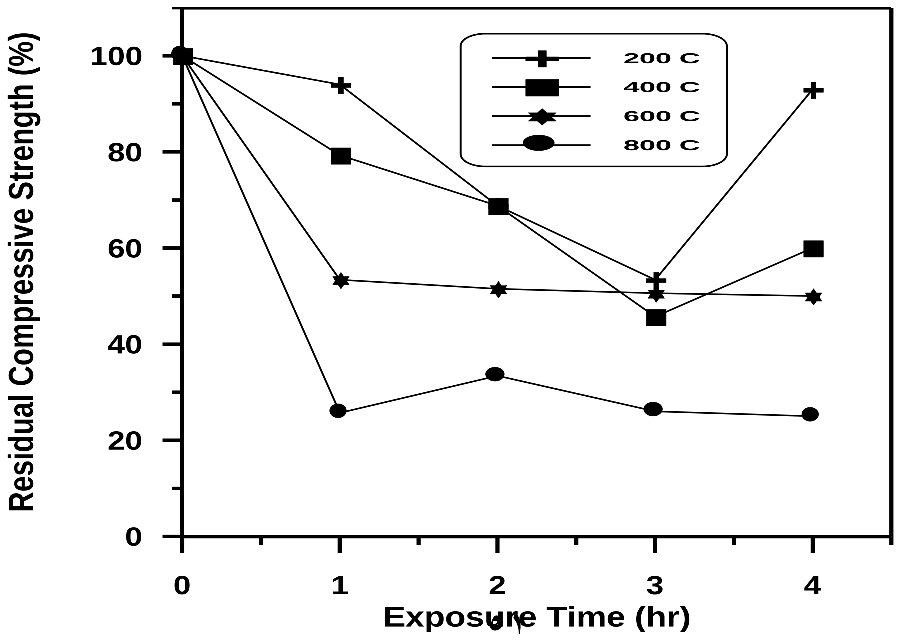


Figure (٢-٥): Effect of exposure time on residual compressive strength of

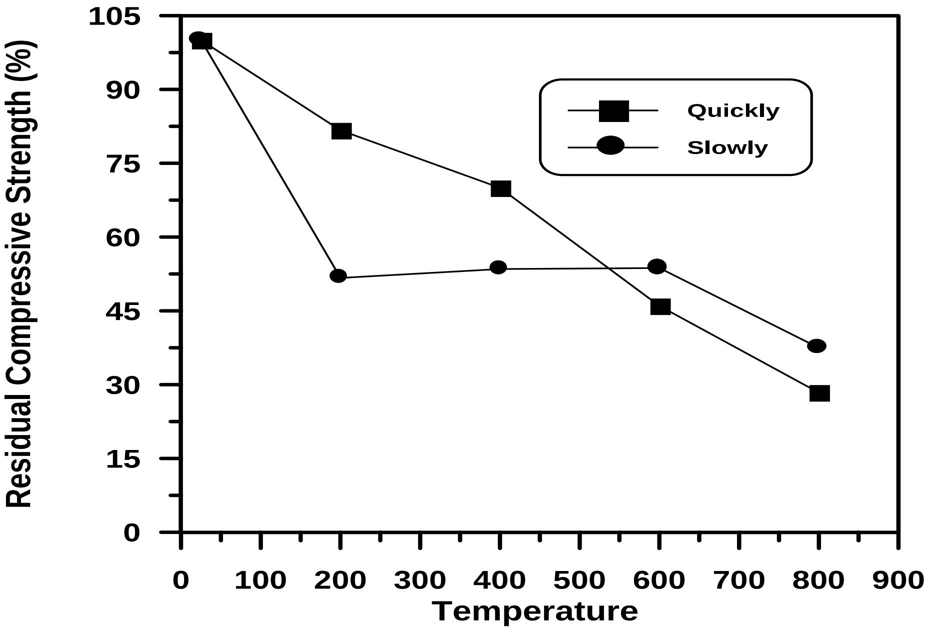


Figure (٢-٦): Effect of rate of cooling on the residual compressive strength of concrete slowly heated[٤٤] .

Harada et al.[٤٥] studied the effect of high temperatures on some mechanical properties of concrete, compressive and tensile strengths. Concrete cylinders of (٥٠*١٠٠)mm were subjected to a slow rate of heating (l.٥°C /min) for one hour duration exposure. The temperature range ٨٠٠ °C) were used.–between (١٠٠

<u>They found that</u>:

١. The reduction in compressive strength was ٦٠٪ at ٤٠٠°C for all types of concrete.

٢. The percentage residual splitting tensile strength was ٨٠,٧٥,٦٠٪ at temperatures of ١٠٠, ٣٠٠, and ٤٥٠°C respectively.

Habeeb G.M. [٤٦] studied the effect of high temperatures on some mechanical properties of high strength concrete (HSC) such as compressive strength, flexural strength and dynamic modulus of elasticity (Ed). Three design strengths were investigated ٤٠, ٦٠ and ٨٠ MPa.. The specimens were heated slowly to five temperature levels (١٠٠, ٣٠٠, ٥٠٠, ٦٠٠ and ٨٠٠ ˚C), and to three exposure periods ١, ٢ and ٤ hours .

<u>He found that</u> :

١. (HSC) is more sensitive to high temperatures than (NSC).The residual compressive strength ranged between (٩٠ – ١٠٦٪) at ١٠٠̊C, (٧٢-١٠٣٪) at ٣٠٠ °C, (٥٥ – ٨٧٪) at ٥٠٠ ˚C and (٢٢-٦٦٪) between (٦٠٠-٨٠٠ ˚C**)**.

٢. The flexural strength was found to be more sensitive to high temperature exposure than compressive strength, the residual flexural strength was in the range of (٩٢ – ٩٨٪), (٥٢-٩٨٪) and (٢٩- ٤٧٪) at ١٠٠̊ C, ٣٠٠̊ C and ٥٠٠ ̊C respectively and (٢-٣٠٪) at ٦٠٠ –٨٠٠ ˚C .

Nuri [٤٧] investigated the effect of high temperatures on some properties of concrete. The specimens were exposed to temperatures in the range of (٢٠-٦٠٠ °C) and the periods of exposure of heating were(٣٠,٦٠ and ٩٠ minutes)at different ages of concrete (٣,٧,٢٨,and ٦٠ days). Concrete cylinders (١٠٢*٢٠٣)mm were used for compressive and splitting tensile strengths.

He found that:

١. After ٣٠٠ °C exposure, concrete retained from (٥٩-١٠٢٪) and (٤٤ – ١٠٠٪) from original compressive and tensile strength respectively.
٢. After ٦٠٠ °C ,concrete retained (٢٨ – ٦٤٪) ,and (٢٠ –٦٢ %) from original compressive and splitting tensile strengths respectively .

***Elizzi* et al.** [٤٨] studied the influence of different temperature on the compressive strength. They used (١٠٠)mm cubes heated for a short duration (one hour) to temperatures ranged (٢٠-١٠٠٠ °C)and the ages of concrete at heating (١٤,٢٨,٩٠ days).

They found that :

١. There was a large strength reduction when the cubes were heated to temperatures above ٤٠٠ °C.
٢. Up to ٤٠٠ °C, the compressive strength decreased ١٠٪ from original.
٣. At ٦٠٠ °C, the compressive strength reduction was ٥٠٪ from original.

***Salla* et al.** [٤٩] studied the effect of temperatures on compressive strength. Concrete cubes(١٠٠)mm with mix (١:١.٥:٣) by weight were used. Three groups of mixes were used. Group (A) have w/c ratio of(٠.٤) by weight with compressive strength about (٤٣)MPa. Group (B) and group (C) have (w/c) ratio of(٠.٥ and ٠.٦) with compressive strength about (٣٦)MPa and (٣٠) MPa respectively. The specimens were heated to four levels of temperatures (١٥٠ , ٣٥٠ ,٥٠٠ and ٧٠٠ °C) for a period (١ hr) and two specimens from each group were tested at room temperature as reference specimens .

<u>They found that:</u>

١. The percentage residual concrete compressive strength for w/c ratio of (٠.٤, ٠.٥ and ٠.٦) were about (٩٤ , ٨٨ and ٨١٪) respectively at (١٥٠ °C), (٨٧,٧٨ and ٧٦٪) respectively at (٣٥٠ °C) and (٦١ , ٦٤ and ٥٣٪) respectively at (٥٠٠ °C).

٢. At ٧٠٠ °C, Three groups of retained about ٣٦٪ from original strength.

Essa.M.S. [٥٠] studied the effect of fire flame on some mechanical properties of concrete such as compressive strength and density. The specimens were heated up to two temperature levels ٥٠٠°C (achieved by subjecting the cubes to direct fire flame from petroleum gas burner) and ٨٠٠ °C (achieved by using an oven). The heating durations were ١ and ٢ hour for the specimens exposed to ٥٠٠ °C, while it was ١ hour for the specimens exposed to ٨٠٠ °C.

<u>He found that</u>

١. At ٥٠٠ °C, the reduction in compressive strength ranged between (٢٣-٣١٪)and ٣٩٪,when the periods of burning were ١ and ٢ hours respectively.

٢. At ٨٠٠ °C, the reduction at ١ hour was ٧٧٪ from the original strength.

<u>٢-٨-٤Effectof High Temperatures on Some Mechanical Properties Using Non- Destructive tests</u>

Two types of non-destructive tests were usually used to evaluate the effects of high temperatures:

١. <u>Schmidt Rebound hammer test</u> :. This test estimates the surface hardness by the rebound number, which can be taken as a measure of the concrete strength and percentage of voids . The test results of rebound number were the average of nine readings to each face [٥١].

٢. <u>The ultrasonic pulse velocity test</u> This test "is a useful tool for assessing the uniformity of concrete and detecting cracks, voids, or honeycombing. It gives useful information about the size of micro – cracked zone and on crack growth and the interior structure of the concrete element" [٥١] .

A number of researches studied the effect of temperature on some destructive tests of concrete.–mechanical properties using the non

Kareem M. M. [٥٢] studied the effect of fire flame on mechanical properties of reinforced concrete slab specimens during and after exposure to fire. She used ultrasonic pulse velocity test and Schmidt Rebound-hammer test .She cast and tested twenty four reinforced concrete slab specimens with dimensions of (٦٠٠*٦٠٠*٤٠)mm divided into two series with target compressive strength of (٣٠ and ٣٨) MPa designated as series A and B respectively.

The specimens were subjected to fire flame at the lower surface only to reach temperatures around (٤٠٠,٥٠٠ and ٦٠٠ °C) for one hour, then they were cooled gradually to room temperature .

<u>She found that:</u>

١. The ultrasonic pulse velocity test showed a response to the fire flame. The reduction in (U.P.V.)was (٢٤-٢٦ %)(٤١-٤٣ %) and (٤٩ -٥١٪)for series (A), while the reduction was (٢٣ -٢٥ %) (٤٢-٤٦٪) and (٤٧-٤٨٪) for series (B) at temperatures of (٤٠٠,٥٠٠ and ٦٠٠ °C) respectively.

٢. The reduction in rebound number was(١٢-١٤٪),(١٩-٢١٪) and (٢٧-٢٩٪) for series (A), while the reduction was (١٢-١٣٪), (١٧-٢٠٪) and (٢٤-٢٦٪) series (B) at temperatures of (٤٠٠,٥٠٠ and ٦٠٠ °C) respectively.

Chung and Law [٥٣] studied the effect of fire damage of concrete by ultrasonic pulse velocity. Prisms (١٥٠*١٥٠*٧٥٠) mm made from concrete of different composition by using granite aggregate were tested. The specimens were heated to different temperatures not exceeding ٥٠٠ °C at age ٢٨ or ٩٠ days. Two types of cooling, some of them were cooled in air, others were quenched in water.

They found that:

١.The reduction in pulse velocity was(٢٨-٣٠٪)(٤٣-٤٧٪) and (٥١-٥٩٪) at temperatures of (٢٥٠,٣٥٠ and ٥٠٠ °C) respectively.

٢. The reduction in pulse velocity beyond ٣٠ percent was accompanied by reduction in strength at faster rate both under air – cooled and quenched conditions.

Logothetis and Economou [٥٤] studied the effect of high temperatures on the properties of concrete using non-destructive methods such as the rebound hammer and pulse velocity. Concrete cubes (٢٠٠) mm were tested .The specimens are consisted of ٣٢ specimens subjected to different curing conditions .The temperatures (٤٠٠,٥٥٠ and ٨٠٠ °C) were used with three periods of exposure (١, ٢ and ٣ hours).

They found that:

١. The reduction in pulse velocity was (٢٨-٣٠٪)(٤٣-٤٧٪) and (٥١-٥٩٪) at (٤٠٠,٥٥٠ and ٨٠٠°C) respectively ,for all period.

٢. The decrease of in Rebound number was about (١٣-١٩٪),(١٥-٢٠٪) and (٢٠-٢٨٪) at(٤٠٠,٥٥٠ and ٨٠٠°C) respectively, for all period.

Purkiss. [٥٦] studied the effect of fire flame on compressive strength of reinforced concrete by ultrasonic pulse velocity test and Schmidt rebound hammer test. Two groups of concrete specimens were used . Group A with w/c ratio of ٠.٥ and mix proportion (١ :٢:٤) and group B with w/c ratio of ٠.٥٥ and mix proportion (١ :١.٥:٣) .

He found that:

١. At (٥٠٠ °C) ,the fire flame leads to reduce the ultrasonic pulse velocity by about (١٦- ٣٢٪) and (٣٩-٥٦٪) for fire durations of period (١ and ٢ hrs) respectively.

٢. At (٨٠٠ °C) , the ultrasonic pulse velocity decreases by about (٥٠٪).

٣. Burning causes to decrease Rebound number by about (١١-١٢٪) and (١٦-٢١٪) for (١ and ٢ hrs)burning durations respectively.

Chapter Three

Materials and Experimental work

٣- ١ General

In this work, three different SCC mixes are investigated. First mix consists (cement ,fine aggregate ,coarse aggregate, super-plasticizer and sand powder as a filler, namely,(MS) . The second mix consists (cement ,fine aggregate ,coarse aggregate, super-plasticizer and crushed limestone powder as a filler, namely,(ML). The third mix consists (cement, fine aggregate, coarse aggregate, super-plasticizer and pigment as a filler, namely,(MP).

The experimental work is divided in two parts: The first part ; is to evaluate properties of the fresh and the hardened concrete properties (compressive ,splitting, flexural strength and modulus of elasticity) in ages ١٤ , ٢٨ and ٥٧ days before firing.

The second part, is studying the effect of exposure to fire flame on some mechanical properties of SCC using different types of filler . The specimens were tested at age ٥٧ days .Three temperature levels of ٣٠٠, ٤٥٠ and ٦٠٠ °C were chosen with three different exposures duration of ٠.٥, ١.٠ and ١.٥ hour.

The destructive tests (compressive , splitting , flexural and modulus of elasticity tests) and two non- destructive tests (the ultrasonic pulse velocity and rebound hammer) were conducted . Three SCC mixes were investigated with a total of(٢٥٠) concrete cubes of (١٠٠)mm,(١٢٠) concrete cylinders (١٠٠*٢٠٠)mm,(١٢٠) concrete cylinders (١٥٠*٣٠٠)mm and (١٢٠) concrete prisms of size (١٠٠*١٠٠*٤٠٠)mm were cast for this purpose.

٣- ٢Materials

٣- ٢-l Cement

The cement used in this study is ordinary Portland cement (OPC) produced by **Ras Al -Khaima** cement factory . Tables (٣-١) and (٣-٣) , show the chemical analysis and the physical properties respectively, of the cement used in this study . Testing of cement was conducted in the laboratories of the Consultant Engineering Bureau in Babylon University. The compliance of the cement is done according to the Iraqi standard No.٥. (IQS ٥:١٩٨٤) for the chemical analysis and for the physical properties specified in this standard .

The four main compounds in Portland cement C٣S, C٢S, C٣A, and C٤AF are calculated for cement specimen using Bogue equations. The results of calculations are listed in Table (٣-٢)

Table (٣-١) Chemical analysis of the cement

Oxide	%	IQS (No.٥:١٩٨٤)
Calcium oxide CaO	٦٣.٩٠	
Silicon dioxide SiO٢	٢٠.٢٦	
Aluminum oxide A١٢O٣	٤. ٨٢	
Ferric oxide Fe٢O٣	٣ .٣٢	
Magnesium oxide MgO	١. ٢١	٥.٠≤
Sulphur trioxide SO٣	٢. ٤٤	٢.٨≤

Loss on Ignition (L.O.I)	٣. ٥٥	٤.٠≤
Lime Saturation Factor (L.S.F.)	٠.٩٤	٠.٦٦-١.٠٢
Insoluble Residue (I.R)	١.٠	١.٥≤

Table (٣-٢) Bogue Potential compound

Tricalcium silicate C٣S %	٥٧. ١٩
Dicalcium silicate C٢S %	١٤. ٩٤
Tricalcium aluminates C٣A %	٧. ١٦
Teteracalciume alumina ferrite C٤AF %	١٠.١٠

Table (٣-٣) physical properties of the cement

Physical properties	Test results	IQS (No.٥:١٩٨٤)
Specific gravity	٣.١٥	
Fineness: specific surface, Blaine . (cm٢/g)	٢٥١٠	>=٢٣٠٠
Setting time(Initial)(min)	١٣٥	>=٤٥ min
Setting time(Final)(min)	٢٤٥	<=٦٠٠ min
Compressive strength, MPa , fc ٣d	١٩	>=١٥
Compressive strength, MPa , fc ٧d	٢٨.١	>=٢٣

٣- ٢- ٢ Fine Aggregate

Natural sand from **AL-Akaidur** region was used. The results of physical and chemical properties of the sand are listed in Table (٣-٤). Its grading conformed to the IQS (No.٤٥:١٩٨٤) .

Table (٣-٤): Properties of fine aggregate.

Sieve size (mm)	Passing %	IQS (No.٤٥:١٩٨٤) Limits
١٠.٠٠	١٠٠	١٠٠
٥.٠٠	٩٦	٩٠-١٠٠
٢.٣٦	٨٥	٨٥-١٠٠
١.١٨	٧٨	٧٥-١٠٠
٠.٦٠	٦٢	٦٠-٧٩
٠.٣٠	٣٠	١٢-٤٠
٠.١٥	٤	٠-١٠
pan	٠	٠
Property	**Results %**	**IQS (No.٤٥:١٩٨٤) Limits**

S۰۳ content	۰.٤۱	۰.٥≤
Clay	۲.۲	۳.۰≤
Specific gravity	۲.٦٥	
Absorption %	۱.٤	

۳- ۲- ۳ ***Coarse Aggregate:***

The coarse aggregate was **AL-Nibaee** gravel with a maximum size of ۱٤ mm. The maximum coarse aggregate size is chosen to be ۱٤ mm,by seving the coarse aggregete of this sieve as shown in Table (۳-٥). The coarse aggregate used in this research is complying IQS (No.٤٥:۱۹۸٤) .

Table (۳-٥): Properties of coarse aggregate.

Sieve size in (mm)	Passing %	IQS(No.٤٥:۱۹۸٤) Limits

٢٠	١٠٠	١٠٠
١٤	١٠٠	٩٥-١٠٠
١٠	٥١	٣٠-٦٠
٥	٩	٠-١٠
pan	٠	٠
Property	**Results %**	**IOS(No.٤٥:١٩٨٤) Limits**
Sulphate content	٠.٠٨	≤٠.١
$So_٣$ %	٢.٦٤	
Specific gravity	٠.٧	
Absorption %		

٣- ٢- ٤ Water

Tab water is used throughout this work for both mixing and curing of concrete.

٣- ٢- ٥ Super- plasticizer

To achieve high workability needed to produce SCC,super-plasticizer known as Ura-plast SP was used in producing SCC.

According to ASTM C٤٩٤-٩٢ , this SP is classified as type F and G, because it has the capability of more than ١٢ % water reduction for a given consistency and it has a retarding effect on the SCC. The normal dosage for the Ura-plast is between ١-٥ liters per ١٠٠ Kg of cement. The typical properties of SP are shown in Table (٣-٦).

Table (٣-٦) :Typical properties of the (super-plasticizers)

Main action	Concrete super plasticizer
Subsidiary effect	Hardening retarded
Form	Viscous liquid
Color	Dark brown
Relative density	١.١ at٢٠°C
viscosity	١ ٢٨+/-٣O cps at ٢٠ °C
pH. Value	٦.٦
Transport	Not classified as dangerous

*Test results is obtained from the manufactor company catologe.

Super plasticizer used in concrete shall conform to the respective requirements of ASTM C٤٩٤, types A and F. The optimum dosage of an Admixture or combination of admixtures should be determined by trial mixtures using varying amounts of admixtures [٥٥].

The super plasticizer is added to the concrete mix in two stages.

A- Mixing (١/٢SP) and (١/٣water), is added to concrete mix after mixing sand, cement, filler, and gravel.

B- Adding (١/٢SP) to the mix of final mixing process better results are obtained when this method is used, since this method gives satisfactory time to cast, and compacts the samples.

٣- ٢- ٦ Limestone Powder (L.S.P)

Finely, crushed limestone which has been brought from local market is used to increase the amount of powder (cement + filler), the fraction less than ٠.١٢٥mm will be of most benefit .

The chemical composition of this limestone is shown in Table (٣-٧) ,tests is conducted in the kufa factory.

Table (٣ -٧) Chemical analysis of the limestone powder

Oxide	%
SiO٢	١.٤٠
Fe٢٠٣	٠.١٧
A١٢٠٣	٠.٧٠

CaO	٥٢.٧٦
MgO	٠.١٠
SO٣	٢.٩١
L.O.I	٤٠.٦٠

٣- ٢- ٧ Pigments

The suitability of pigments used in SCC is established in EN ١٢٨٧٨ and used in concrete permitted by BSEN ٢٠٨-١,٥.١.٦ pigments for the coloration of building, and filling material to improve the properties of fresh and hardened concrete. This material is brought from local market, then it is used in the concrete mixes after passing sieve size ٠.٠٧٥ mm. The chemical composition of the pigment is shown in Table(٣-٨),which is conducted in the kufa cement factory.

Table (٣ -٨) Chemical analysis of the pigment

Oxide	%
SiO٢	٤.١٧
Fe٢٠٣	٠.١٠
A١٢٠٣	٠.٥٠
CaO	٦٣.٠٨
MgO	٠.١٢

$SO_٣$	٠.٦٣
L.O.I.	٣١. ٢٦

٣- ٢-٨ Sand Powder

Filler aggregate which conforms to EN ١٢٦٢, has been used in concrete permitted by BSEN ٢٠٦-١, ٥.١.٦. In this case, a natural sand material of particles less than ٠.٠٧٥mm is used as filler, which is from the same sand used as a fine aggregate in the concrete of this work.

٣- ٣ Mix Proportion

The SCC mix Proportions are summarized in Table (٣-٩).Mix is chosen according to the Japanese mix design system.

Table (٣ -٩) Mix Proportion

Materials	Contents	Limitations ($Kg/m^٣$)
Cement ($Kg/m^٣$)	٤٠٠	٣٥٠-٤٥٠
Fine aggregate ($Kg/m^٣$)	٧٢٠	٧٠٠-٩٥٠
Coarse aggregate ($Kg/m^٣$)	٨٠٠	٧٠٠-٩٠٠
Filler ($Kg/m^٣$)	٨٠	٥٠-١٥٠
(Water / powder) ratio	٠.٥٢	٠.٣٣-٠.٦٢

S .P. (Liter/١٠٠Kg cement)	٤	١-٥

٣-٤ Mixing of Concrete:

The mix Proportions of self-compacting concrete discussed in Table (٣-٩), are prepared by accurate weighing. The procedure used for mixing the batches is as follows [٦]:

١. Predetermined quantities of fine aggregate (sand) and ١/٣ water were added to the mixer and mixed for ١ minute.

٢. Predetermined quantities of cement, filler and ١/٣ (water plus SP) were added to the mixer and mixed together for ٣٠ sec.

٣. A half of the gravel and ١/٣ (water plus S.P.) were added and mixed for ٣٠ sec.

٤. The final half of gravel and ١/٣ SP were added to the mixer and mixed for ١ minute as shown in Figure (٣-١)

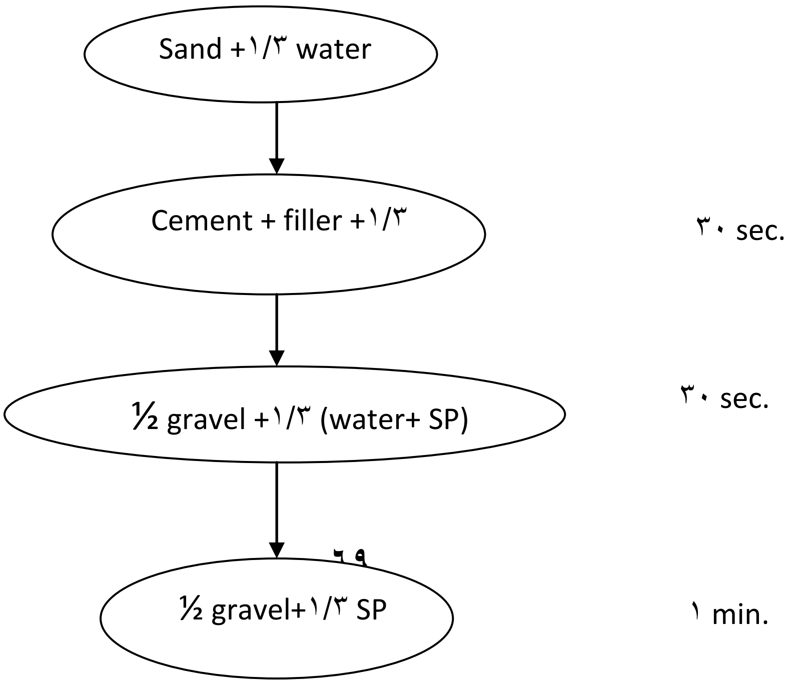


Figure (٣ -١): Mixing procedure.

No vibration or compaction has been applied to the SCC specimens.This method was chosen according to the limitions of mixing taken by others [٥] .

٣- ٥ Testing of Fresh Concrete:

It is important to appreciate than none of the test methods for SCC has yet been standardized, and the tests described are not yet perfected or definitive[٢١].The methods presented here are descriptive rather than fully detailed procedures, which have been devised specially for SCC. In considering these tests, there are a number of points which should be taken into account:

١. One principal difficulty in devising such tests is that they have to assess, three distinct , thought related , properties of SCC its filling ability (flow ability), its passing ability (Pass ability) and its segregation resistance (stability). No single test so far devised can measure all three properties.
٢. There is no clear relation between test results and performance at site.
٣. The test methods and values are stated for max. aggregate size of up to ٢٠ mm; different test values and/or different equipment dimensions may be appropriate for other aggregate sizes.

٣-٥-١ Slump Flow Test and T٥٠ cm Test:

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions (flowability, stability)[٦] , as shown in Figure (٣-٢).

Procedure

١. We are needed About ٦ litters of concrete to perform the test.
٢. The base plate was moisten and the inside of slump cone.
٣. Base plate was laced on level stable ground and the slump cone centrally on the base plate and that a concentric diameter of ٥٠٠ mm is marked on the plate.
٤. The cone was fill with the scoop, do not tamp, simply strike of the concrete level with the top of the cone with trowel.
٥. Remove any surplus concrete from around the base and cone.
٦. The cone was raised vertically and allow the concrete to flow out freely.
٧. The stop watch was recorded the time taken for concrete to reach the ٥٠٠ mm spread circle, (this is $T٥٠_{cm}$).
٨. **T**he final diameter was measured of concrete in two perpendicular directions.

٩. Calculate the average of the two measured diameters, (this is slump-flow in mm).

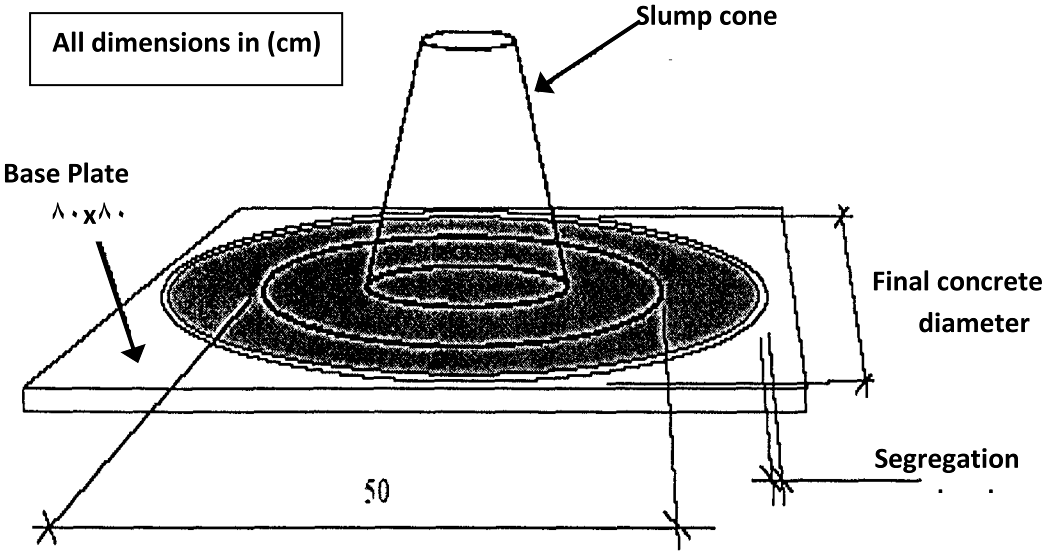


Figure (٣-٢) The slump flow test[٤]

٣-٥-٢ L-Box Test:

This test assesses the flow of concrete, and also extent to which it is subjected to blocking by reinforcement. It indicates the slope of concrete when at rest. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted. This apparatus is made according to the Japanese design for under water concrete described by Petersson [٥٧], as shown in Figure (٣-٣) [٦].

Procedure

١. The apparatus was set level on firm ground, ensure that the sliding gate can open freely and then close it.

٢. The inside surface of the apparatus was moisten and remove any surplus water.

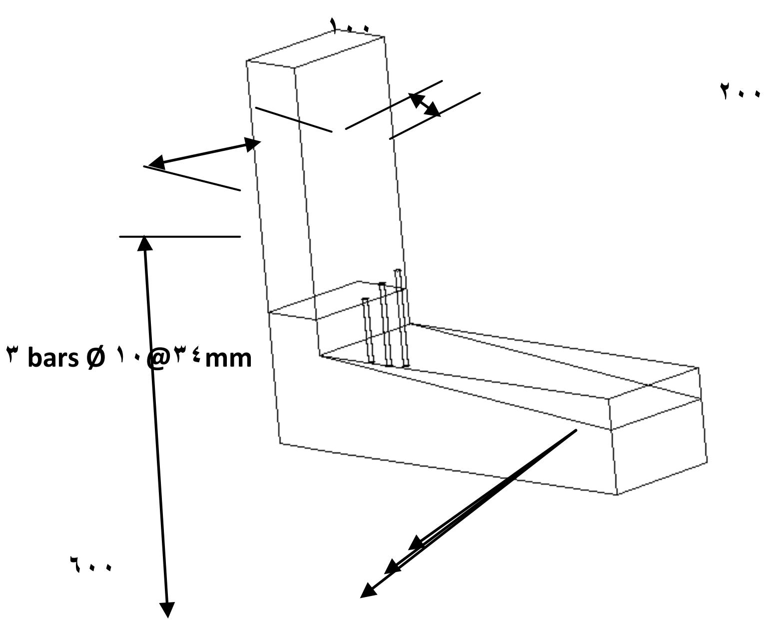
٣. The vertical section of the apparatus was filled with ١٢.٧ liters of concrete.

٤. It was leaved to stand for ١ min.

٥. The sliding gate was lift and allow the concrete to flow out into the horizontal section.

٦. The distance H١ and H٢ was measured ,when concrete stops flowing.

All dimensions in (mm)



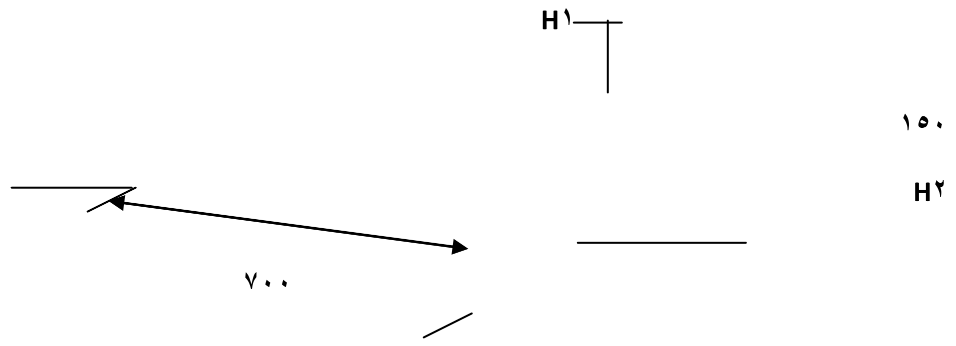


Figure (٣-٣): L-box test [٤].

٣-٥-٣ U- Box Test:

This test is used to measure the filling ability of SCC. According to the technology research centre of the Taisei Corporation in Japan [٥٨].

Procedure

١. The apparatus was set on firm ground, ensure that the sliding gate can open freely and then close it.

٢. The inside surface of the apparatus was moisten, remove any surplus water.

٣. The compartments of the apparatus was fill with ٢٠ liters of concrete.

٤. It left to stand for ١ min.

٥. The sliding gate was lift and allow the concrete to flow out into the other compartment.

٦. When concrete is rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean H١. Measure also the height in the other compartment H٢ as shown in Figure(٣-٤).

٧. Calculate (H١-H٢), the filling height.

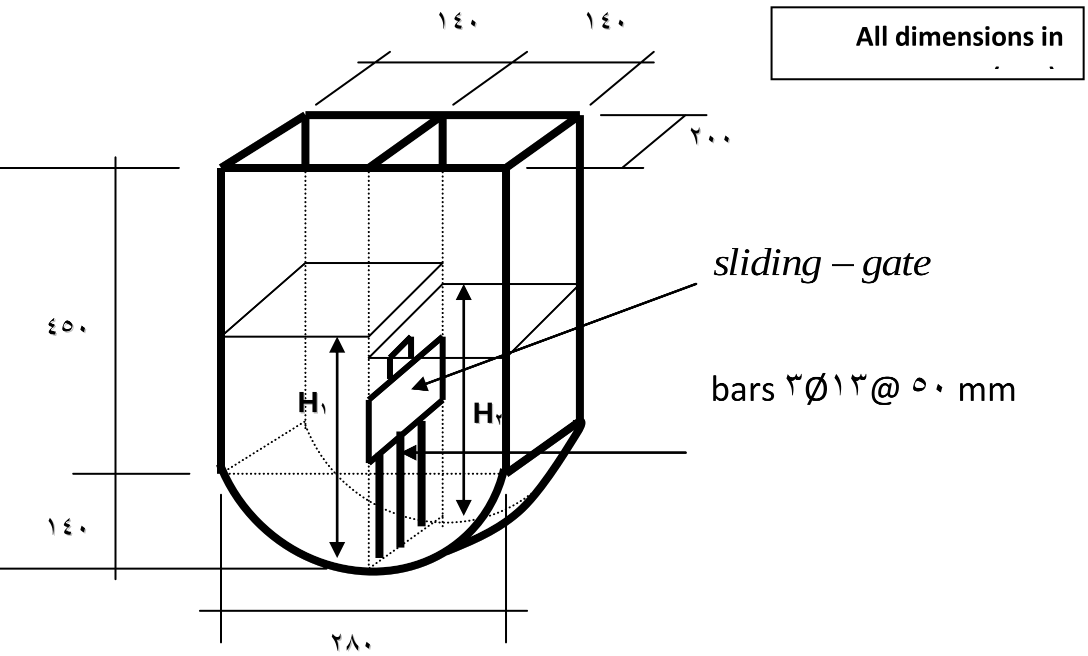


Figure (٣-٤) The U-box test [٤] .

٣- ٥ – ٤ V-Funnel Test:

The V-funnel test is used to determine the filling ability of the concrete with a maximum aggregate size of ٢٠ mm . This apparatus is made according to the Japanese efforts by ***Okamura*** **et. al** [٥٩].

Procedure

١. The V-funnel was set on firm ground.

٢. The inside was moisten surface of the funnel.

٣. The trap door was opened to allow any surplus water to drain.

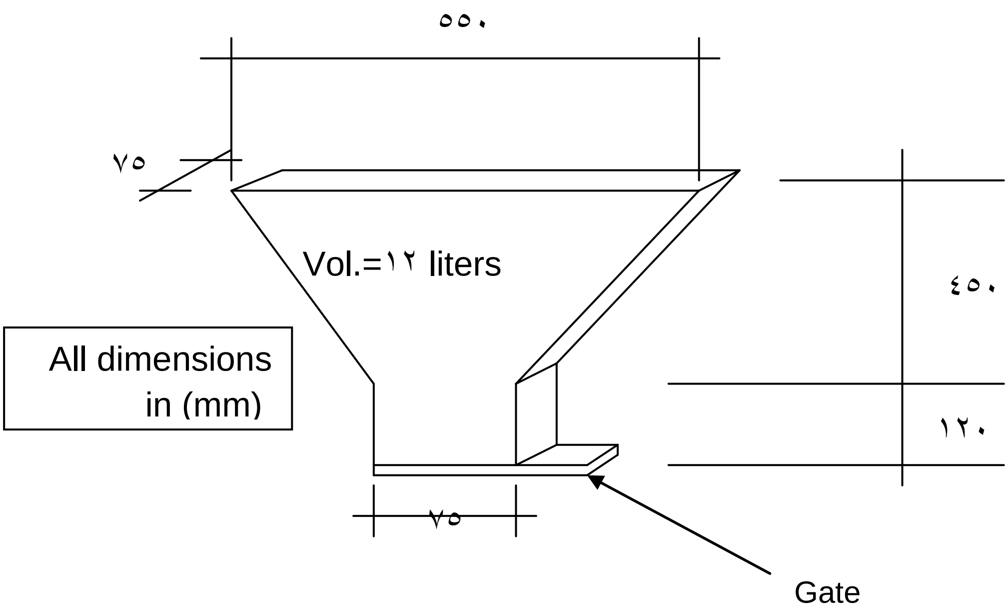
٤. The trap door was closed and placed a bucket underneath.

٥. The apparatus was fill shown in Figure (٣-٥) completely with concrete without compaction or tamping; simply strike off the concrete level in the top with trowel.

٦. The trap door was opened within ١٠ sec to flow out under gravity.

٧. The stop watch was recorded the time for the discharge to complete (the flow time).

Figure (٣ -٥): The V-funnel test [٦].



٣- ٦ Curing Conditions:

Since, SCC was made with three types of filler (sand powder, limestone powder and pigment) as filler materials. Moist curing in water until the age of ٢٨ day , and left in air until the age of ٥٧ days.

٣- ٧ Heating And Cooling Procedure

The concrete specimens were burnt with direct fire flame from a network of methane burners with dimensions of (١٠٠٠*١٠٠٠)mm as shown in Plate (٣-١(A)) and Plate (٣-١(B)) inside a brick stove. The fire flame was intended to simulate the heating condition in an actual fire .The intensity of the flame was adjusted to raise the specimens to different temperatures. The target temperature peratures were continuously recorded by two thermometers, one of them was positioned in flame contact with the bottom surface , while the other was at top surface of the specimen as shown in Plate (٣-٢) .

After burning , part of the concrete specimens was allowed to cooling inside the stove for ٢ hours after the end of firing and stored in the laboratory environment about ٢٤ hours. The other specimens were quenched immediately in water for ٢ hours and then stored in laboratory environment about ٢٤ hours also before testing.

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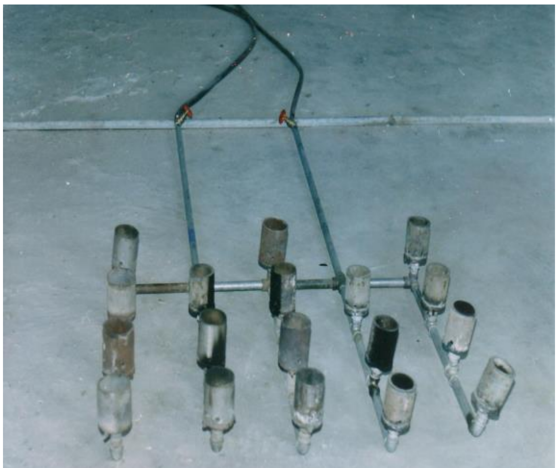

Plate (٣-١) the net work of burners

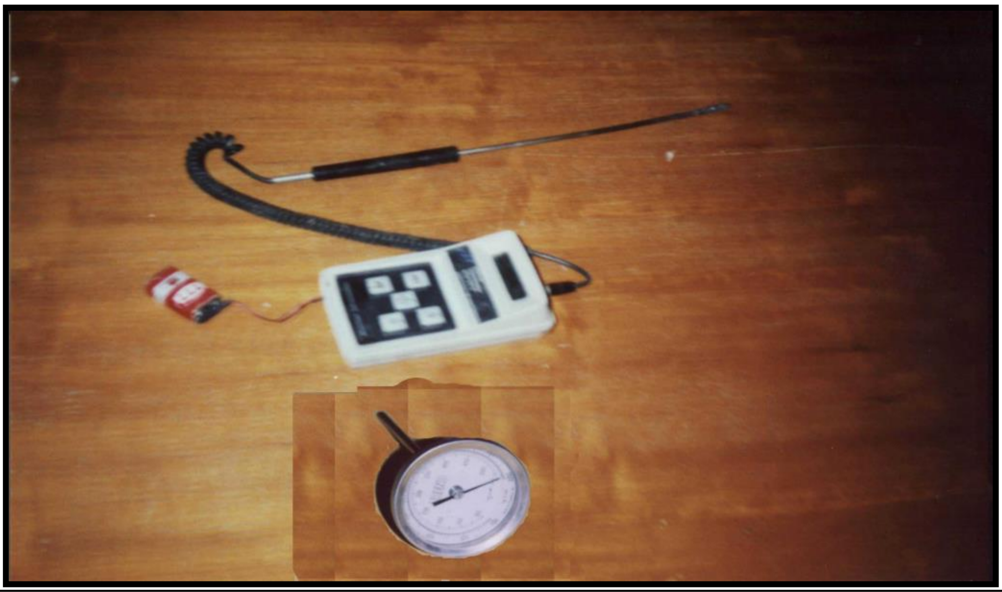

Plate (٣-٢) the two thermometers

٣-٨ Hardened Concrete Tests:

٣-٨-١ Compressive Strength Test:

Compressive strength was carried out and tested according to BS ١٨٨١: part ١١٦:١٩٨٣ . A total number of ٢٥٠ cubes of (١٠٠) mm were tested by using a hydraulic compression machine of ٢٠٠٠ kN. All specimens were cured in water until testing age (٥٧ days). Each result of compressive strength obtained is the average of three specimens.

٣-٨-٢ Splitting Tensile Strength Test:

The splitting tensile strength was determined according to the procedure outlined in BS ١٨٨١: part ١١٧: ١٩٨٣. A total number of ١٢٠ cylinders (١٠٠*٢٠٠) mm were tested at (٥٧) days. Cylinders were cast, demolded ,cured and tested in a similar way as for cubes. Each splitting tensile strength result is the average of strength for two specimens. The splitting tensile strength is calculated from the equation[٢٦]:

$$\sigma = \frac{2P}{\pi LD} ---------- (3-1)$$

where:

P=the applied compressive load. N

L=the cylinder length. mm

D=the cylinder diameter. mm

٣-٨-٣ Flexural Strength Test:

Concrete prisms of dimensions (١٠٠*١٠٠*٤٠٠) mm were cast according to BS ٥٣٢٨:٤:١٩٩٠ procedure. A total number of ١٢٠ prisms were tested. The prisms were cast, demolded and cured in a similar manner as for cubes. Modulus of rupture test was conducted according to BS١٨٨١:١١٨:١٩٨٣ using two-point load as shown in Figure (٣-٧).

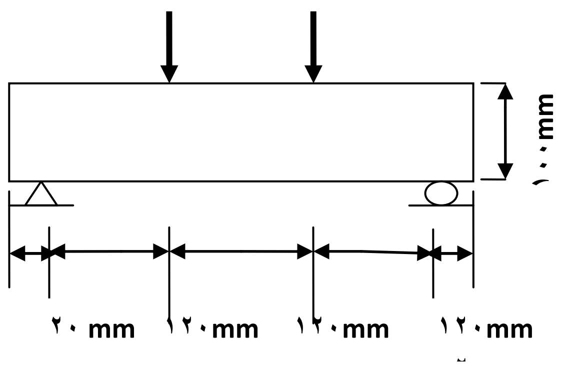

Figure (٣-٦): Two-point load flexural strength test.

Each value of the modulus of rupture is the average of the test results for two specimens. Modulus of rupture is calculated from the simple beam bending formula [٢٦]:

$$R = \frac{pl}{bd^2} ----------(2-2)$$

Where:

p=maximum applied load ,N , l=span length, mm

b=specimen width , mm , d=specimen depth, mm

This equation is valid only if failure line is within the middle third span. If failure line is outside middle span by not more than ٥ % of the span length, the equation below is used (٢٦):

$$R = \frac{3pa}{bd^2} ----------(2-3)$$

Where:

a=the average distance between the point of fracture and the nearest support.

٣-٨-٤ Static Modulus of Elasticity:

The static modulus of elasticity was determined according to BS ١٨٨١:١٢١:١٩٨٣ specification. A total number of ١٢٠ cylinders (١٥٠*٣٠٠) mm

were tested. All specimens were castand cured as for the compressive strength cubes. A hydraulic compression machine of ٢٠٠٠ kN is used to apply a compression load until ٤٠ % of the ultimate load . The clamping rings used which have a gauge length of ٢٠٠ mm and gauge with an accuracy of ٠.٠١ mm, is made according to BS ١٨٨١:١٢١:٨٣. The recorded results were the average of readings for two cylinders. The modulus of elasticity is calculated as follows[٢٦]:

$$E_c = \frac{S_2 - S_1}{\varepsilon_2 - \varepsilon_1} --------(3-4)$$

Where:

E_c=modulus of elasticity GPa.

S٢=stress corresponding to ٤٠ % of ultimate load GPa.

S١=stress corresponding to the longitudinal strain of ٥٠*١٠-٦ GPa.

ε_2 =longitudinal strain produced by S٢.

ε_1 =٥٠*١٠-٦

٣-٨-٥ Non –Destructive Tests:

٣-٨-٥-١ Ultra –Sonic Pulse Velocity:

Ultrasonic Pulse transit times were measured by direct transmission method . This test was carried out according to ASTM C٥٩٧[٥١].The Velocity of Ultrasonic Pulse transmitted through the cubes specimens was determined before and after burning.Portable ultrasonic concrete tester known as (PUNDIT) ٥٤ KHz was used for this purpose as shown in Plate (٣-٣).

Calibration of the PUNDIT was done before testing to check the accuracy of the transit time measurements. This was achieved by the calibration by the reference bar.

A thin layer of grease was applied on the surface to act as a couplant and to prevent dissipation of transmitted energy.

The Pulse transit path length was measured accurately and the time of its traveling was recorded to the order of ٠.١ microsecond.

Pulse velocity ,V, in km/sec is calculated as follows [٥١]:

$$V = \frac{L}{T} ------------(3-5)$$

Where :

V = Ultra-sonic pulse velocity, km/sec.

L = path length , mm .

T = transit time , microsecond.

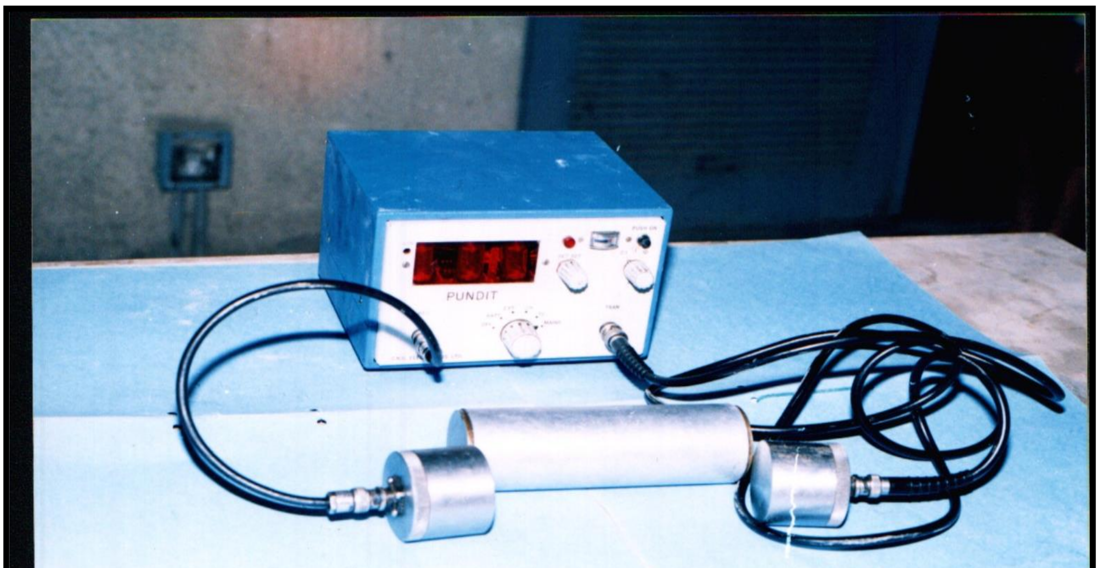

Plate (٣-٣): Ultrasonic pulse transit time apparatus

٣-٨-٥-٢ Schmidt Rebound Hammer Test:

Schmidt Rebound hammer was used to estimate the hardness of concrete specimens by recording the rebound number , which could be used as a measure of the concrete strength and percentage of voids. The test method is prescribed by BS ١٨٨١: ٢٠٢:١٩٨٦ specifications. The test results of rebound number are the average of nine readings to each face. The mean rebound number was calculated for each specimen before and after burring[٥١]. Schmidt hammer is shown in Plate (٣-٤).

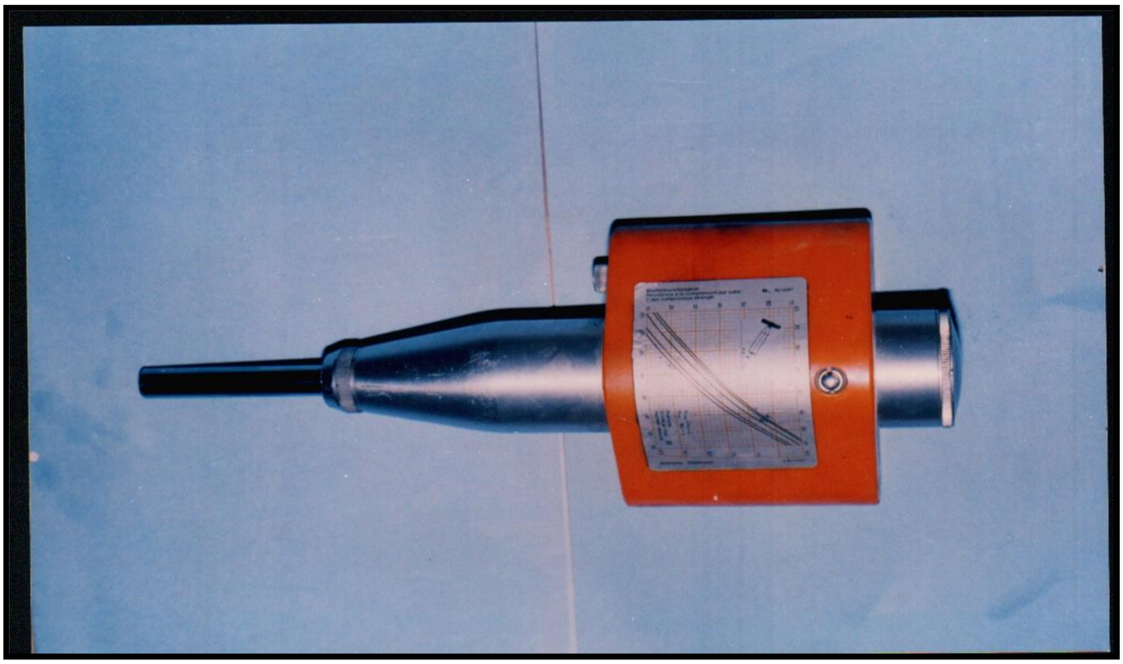

Plate (٣-٤) : Rebound hammer apparatus .