# Properties of High-Strength Fibrous Concrete With Crushed Stone as Coarse Aggregate

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**Keywords:** High-strength, Steel fiber, Crushed stone, Concrete

## Abstract:

The influence of volume fraction of steel fiber, amount of crushed stone and type of mixes on the compressive, splitting tensile and flexural strength (modulus of rupture) of high-strength concrete has been studied in this investigation.

Results showed that the increase of (١%) in volume fraction of steel fiber cause an increase in the compressive, splitting tensile and flexural strength (modulus of rupture) by ١٣.٣%, ٦٧.٥% and ٤٠.٦% respectively for natural aggregate, while increase by ٤.٨%, ٤٦.٧% and ٢٩.٨% for crushed stone aggregate respectively . Also one can use crushed stone instead of natural gravel especially in places where no natural gravel is available.

## Notation:

$f'_c$ : Concrete compressive strength (MPa)

$f_{ct}$ : Concrete splitting tensile strength (MPa).

$f_r$ : Concrete modulus of rupture (MPa).

$V_f$ : Volume fraction of steel fiber (%)

## Introduction

Concrete having cylinder compressive strength exceeding ٤١ MPa is designated as high-strength concrete[١]. In recent years, the use of high-strength concrete has become increasingly popular. It is technically and economically feasible to produce ready-mixed high-strength concrete using conventional methods and materials. The high-strength concrete offers significant economic and architectural advantages over ordinary concrete and also is suited for special constructions that required high durability and leads to the design of smaller sections, this in turn reduces the dead weight allowing longer spans and more usable area of building[٢].

High-strength concrete is a brittle material. The increase in concrete strength reduces the ductility. This inverse relation between strength and ductility is a serious drawback for the use of high-strength concrete and a

Compromise between these two characteristics of concrete can be obtained by adding discontinuous fibers[٣]. The idea of using discrete ductile fibers to reinforce brittle materials such as concrete is not new with many studies having been undertaken over the past four decades. Early studies by Romualdi and Batson[٤] in the United States in the early ١٩٦٠ indicated that the tensile strength of concrete can be improved by providing suitably arranged and closely spaced wire reinforcement.

Many researches have been carried out on the use of crushed aggregate or crushed stone concrete containing fibers [٥-٩], and others on the properties of normal and high-strength fiber reinforced concrete[١٠-١٦].

Aggregate has an important role in the matrix, because about three-quarter of the mixture include coarse aggregate, and since there are many places were natural gravel is not sufficiently available, so one can replace it by crushed stone, or now due to the increasing new projects in Iraq especially in Iraq Kurdistan Region, making concrete will requires great quantities of gravel. This will cause a great reduction of this material during the next few years in the region which will have a bad effect on the development and also on the economy. The main objective of this investigation is to study the effect of volume fraction of steel fiber, crushed stone content as coarse aggregate on the compressive, splitting tensile and flexure (modulus of rupture) strengths of high-strength fibrous concrete.

## Experimental program

The test program consists of casting and testing ٩٠ standard cylinder specimens (١٥٠mm *٣٠٠mm) to study the compressive and splitting tensile strength of concrete. Also, ٤٥ prism specimens (١٥٠mm *١٥٠mm *٥٠٠mm), were tested under two-point loads (third point loading) to study the modulus of rupture of high-strength concrete.

The specimens were divided into ٥ groups as shown in Table (١). Mix A (١:١.٥:١.٥) contains three subgroups to study the volume fraction of steel fibers with different crushed stone aggregate contents and their effects on compressive, splitting tensile strengths and modulus of rupture, while mix B (١:١.٥:٢) and C (١:٢:٢) contain one group for each mix to study the effect of volume fraction of steel fibers on the strength of high-strength concrete with crushed stone as coarse aggregate.

## Materials

*Ordinary Portland cement:* The cement used in the investigation from Marden Turkish Company with fineness ٣١٤٠cm$^2$/gm (Blaine method), initial setting time١٤٠ minutes and final setting time was ٣.٥ hours (Vicat apparatus).

*Natural sand:* The sand used from Khankey pit (Duhok Government) having a fineness modulus ٢.٧٤ and specific gravity equal to ٢.٧ with good gradation.

*Natural gravel:* The gravel with maximum size ٩.٥mm and specific gravity equal to ٢.٧١ from Khankey pit was used as coarse aggregate.

*Crushed stone (limestone):* Lime as coarse aggregate, near Lumana village in Duhok was used with the following properties: In general it is of white color, medium rough-surface, angular shape, absorption ٢.٠٧%, specific gravity ٢.٦٦ and loss of ignition equal to ٤٣.٠٧.

*Steel fibers:* Smooth steel fibers used were of ٠.٢mm in diameter and ٢٠mm in length (aspect ratio=١٠٠) from National British Company, with ultimate tensile strength of ١١٥٠ MPa.

*High water-reducer (superplastisizer) millamin-١٠: and drinking water.*

## Casting and curing

Rotary concrete mixer with ٠.١ m$^3$ was used for mixing the concrete, also an electric vibrator used for compaction. Aggregate were mixed with cement dry inside the mixer for nearly one minute, then water was added to the mixture after re-solved the super-plasticizer powder in it,

| Speci | $V_f$ % | Slump (mm) | Remarks |
|---|---|---|---|
| AN١ | ٠ | ٣١ | Mix( A)ratio ١:١.٥:١.٥ (natural aggregate), w/c = ٠.٣٥+١.٥% superplastisizer |
| AN٢ | ٠.٥ | ٢٥ | |
| AN٣ | ١ | ٢٠ | |
| ANC١ | ٠ | ٢٤ | ٥٠% Crushed stone content |
| ANC٢ | ٠.٥ | ٢٠ | |
| ANC٣ | ١ | ١٦ | |
| AC١ | ٠ | ٢٢ | ١٠٠% crushed stone content |
| AC٢ | ٠.٥ | ١٧ | |
| AC٣ | ١ | ١٤ | |
| BC١ | ٠ | ١٨ | Mix( B )ratio ١:١.٥:٢ (١٠٠% crushed stone content), w/c =٠.٣٥+١.٥% superplastisizer |
| BC٢ | ٠.٥ | ١٤ | |
| BC٣ | ١ | ١١ | |
| CC١ | ٠ | ١٤ | Mix( C )ratio ١:٢:٢ (١٠٠% crushed stone content), w/c= ٠.٣٥+١.٥% superplastisizer |
| CC٢ | ٠.٥ | ١١ | |
| CC٣ | ١ | ٧ | |

spreading the steel fibers by hand inside the mixer to avoid balling and to attain a homogenous mixture.

*Table ١: Details of Tested Specimens*

First letter refers to type of the mix.
Second letter refers to type of aggregate.
N: Natural aggregate. C: Crushed stone aggregate

The moulds which are used were oiled first. The cylinder specimens were cast in three layers and each layer compacted by the vibrator until no further air bubbles appeared on its surface, while the beam specimens were cast in two layers and compacted as the same manner. After ٢٤ hours the specimens were demoulded and submerged in clean fresh water for ٢٨ days.

## Testing specimens

***Compressive strength testing:*** The cylinder specimens were placed vertically under test, then capped by the machine caps and the load was applied without shock and increasing continuously at the constant rate (٠.٥MPa/s) until failure. Fig.(١) shows the testing specimen under the compression machine.

***Splitting tensile strength testing:*** In this test, a concrete cylinder specimen was placed with its axis horizontal between the platens of a testing machine, and the load increased until failure by indirect tension in the form of splitting along the vertical diameter occurred.

***Flexural strength testing:*** In this test, a concrete beam was subjected to flexural using symmetrical two point loading until failure occurred. Fig.(٢) shows the specimen under the rupture testing machine.

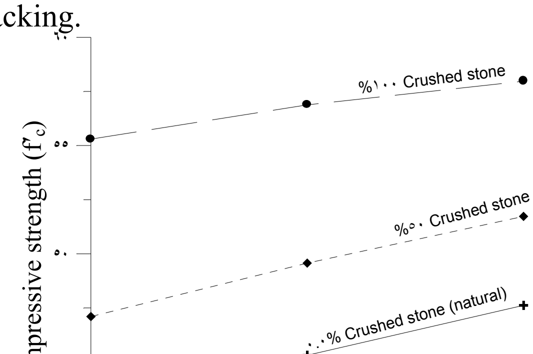
**Fig. (١): Compression machine**

**Fig. (٣): Rupture testing machine**

**Results and Discussion**

The values of ultimate compressive, splitting tensile and flexural strengths obtained from experimental tests and ACI formulas are listed in Table (٢). All strengths were increased by increasing of volume fraction of steel fiber for both natural gravel and crushed stone concrete as shown in (Figs.٣, ٤ and ٥). The compressive strength was increased by (١٣.٣%, ٩.٨% and ٤.٨%) and splitting tensile strength was increased by (٦٧.٥%, ٥٦.٩% and ٤٦.٧%) while the flexural strength (modulus of rupture) increased by (٤٠.٦%, ٣٣.٧% and ٢٩.٨%) for crushed stone content (٠%, ٥٠% and ١٠٠%) respectively. This means that the effect of steel fiber on the natural gravel high-strength concrete was more than the crushed stone high-strength concrete, this is due to suitable workability for first mix compared with the second one as shown in Table (١). Also results showed that the average increase in compressive strength of ١٣.٣% for natural gravel and ٤.٨% for crushed stone when volume fraction of steel fiber increased from ٠.٠% to ١.٠% and for tensile strength ٦٧.٥% & ٤٦.٧%, while the flexural strength is increased by ٤٠.٦% and ٢٩.٨% for both natural gravel and crushed stone. The increase in compressive strength was small when compared with splitting tensile and flexural strengths due to different mechanisms in three cases and this is a good agreement with the results of the other researches [٦, ٨, ١٠]. Also these figures indicate that the concrete strengths increased by increasing the crushed stone content. Figures (٦, ٧ and ٨) show a comparison between mixes (A, B and C) for different volume fraction of steel fibers and show that the first mix has greater strength compared with the other two mixes, because the cement/aggregate ratio is the higher one. At last, Figs. (٩, ١٠ and ١١) show the relationship between the ratios of ($f'_c/f_{ct}$, $f'_c/fr$ and $f_{ct}/fr$) and volume fraction of steel fibers ($V_f$) for different percentages of crushed stone content. These figures indicate that the $f'_c/f_{ct}$ and $f'_c/fr$ ratios decreased by increasing $V_f$, while the $f_{ct}/fr$ ratio increased by increasing $V_f$ and that is due to the compressive strength being less affected than the splitting tensile and flexural strengths by $V_f$. Table (٢) also show the computed values of splitting tensile strength and modulus of rupture for concrete using ACI-Code formulas. The values which are obtained from testing of specimens in general were higher than the values computed from ACI- formulas especially for steel fibrous concrete, because these formulas do not take into consideration the contribution of steel fibers, this contribution exceeds ٥٤%for splitting tensile concrete strength and ٣٨% for modulus of rupture, while one can be applied these formulas for high-strength crushed stone concrete without steel fibers.

Modulus of rupture test results of HSC beams showed that, beams without fiber had little ductility, and once the maximum tensile stress was reached, the beams failed suddenly after the occurrence of the first crack without warning. The failure characteristics were however, completely changed as a result of the addition of fibers. After the occurrence of initial cracking, the specimen did not fail suddenly. The randomly oriented fibers crossing the cracked section resisted the propagation of cracks and separation of the section. This caused an increase in the load-caring capacity beyond the first cracking.



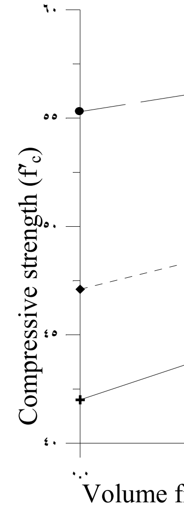




Fig. ٣: Compr
volume fra

*Table ٢: Compressive, Splitting Tensile Strengths  and Modulus of Rupture of the Tested Specimens.*

| Speci | $V_f$% | $f'_c$ | $f_{ct}$ | ACI $f_{ct}$ | $f_{ct}$/ ACI $f_{ct}$ | $f_r$ | ACI $f_r$ | $f_r$/ ACI $f_r$ | $f'_{ct}$ /$f_t$ | $f'_c$ / fr | $f_{ct}$ / $f_r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AN١ | ٠ | ٤٢.٠ | ٣.٧٥ | ٣.٨٢ | ٠.٩٨ | ٦.٣٦ | ٦.٠٩ | ١.٠٤ | ١١.٢ | ٦.٦ | ٠.٥٩ |
| AN٢ | ٠.٥ | ٤٥.٣١ | ٤.٩٨ | ٣.٩٧ | ١.٢٥ | ٨.٤٥ | ٦.٣٣ | ١.٣٣ | ٩.١٠ | ٥.٤٢ | ٠.٦٠ |
| AN٣ | ١ | ٤٧.٦٢ | ٦.٢٨ | ٤.٠٧ | ١.٥٤ | ٨.٩٤ | ٦.٤٨ | ١.٣٧ | ٧.٥٨ | ٥.٣٣ | ٠.٦٦ |
| ANC | ٠ | ٤٧.١ | ٤.١١ | ٤.٠٥ | ١.٠١ | ٧.٠١ | ٦.٤٥ | ١.٠٩ | ١١.٤٦ | ٦.٧١ | ٠.٥٩ |
| ANC | ٠.٥ | ٤٩.٥٧ | ٥.٣٥ | ٤.١٥ | ١.٢٨ | ٨.٦٠ | ٦.٦١ | ١.٣٠ | ٩.٢٥ | ٥.٧٦ | ٠.٦٢ |
| ANC | ١ | ٥١.٧٣ | ٦.٤٥ | ٤.٢٤ | ١.٥٢ | ٩.٣٧ | ٦.٧٦ | ١.٣٨ | ٨.٠٢ | ٥.٥٢ | ٠.٦٩ |
| AC١ | ٠ | ٥٥.٣ | ٤.٧١ | ٤.٣٨ | ١.٠٧ | ٧.٤٩ | ٦.٩٩ | ١.٠٧ | ١١.٧٤ | ٧.٣٨ | ٠.٦٣ |
| AC٢ | ٠.٥ | ٥٦.٨٨ | ٥.٧٥ | ٤.٤٤ | ١.٢٩ | ٨.٩١ | ٧.٠٩ | ١.٢٥ | ٩.٨٩ | ٦.٣٨ | ٠.٦٥ |
| AC٣ | ١ | ٥٧.٩٨ | ٦.٩١ | ٤.٤٩ | ١.٥٤ | ٩.٧٢ | ٧.١٦ | ١.٣٥ | ٨.٣٩ | ٥.٩٧ | ٠.٧١ |
| BC١ | ٠ | ٥٥.٣ | ٣.٩٨ | ٤.٣٨ | ٠.٩٠٧ | ٦.٩٣ | ٦.٩٩ | ٠.٩٩ | ١٣.١٤ | ٧.٥٥ | ٠.٥٧ |
| BC٢ | ٠.٥ | ٥٥.٧٢ | ٤.٨٩ | ٤.٤ | ١.١١ | ٨.٠٢ | ٧.٠١ | ١.١٤ | ١٠.٩٩ | ٦.٧٠ | ٠.٦١ |
| BC٣ | ١ | ٥٦.٨٣ | ٦.١٢ | ٤.٤٤ | ١.٣٧ | ٨.٩٢ | ٧.٠٨ | ١.٢٥ | ٩.١٢ | ٦.٢٦ | ٠.٦٩ |
| CC١ | ٠ | ٤٩.٤ | ٣.٨١ | ٤.١٤ | ٠.٩٢ | ٦.١٢ | ٦.٦٠ | ٠.٩٢ | ١٢.٩٦ | ٨.٠٨ | ٠.٦٢ |
| CC٢ | ٠.٥ | ٥٠.٧٧ | ٤.٢٦ | ٤.٢ | ١.٠١ | ٦.٧٠ | ٦.٦٩ | ١.٠٠ | ١١.٩٢ | ٧.٥٨ | ٠.٦٤ |
| CC٣ | ١ | ٥٢.٤ | ٥.٨٢ | ٤.٢٧ | ١.٣٦ | ٧.٦٢ | ٦.٨ | ١.١٢ | ٩.٠٠ | ٦.٨٨ | ٠.٦٨ |

$f_{ct} = ٠.٥٩\,(f'_c)^{١/٢}$ ……………………(MPa)

$f_r = ٠.٩٤\,(f'_c)^{١/٢}$ ……………………(MPa)

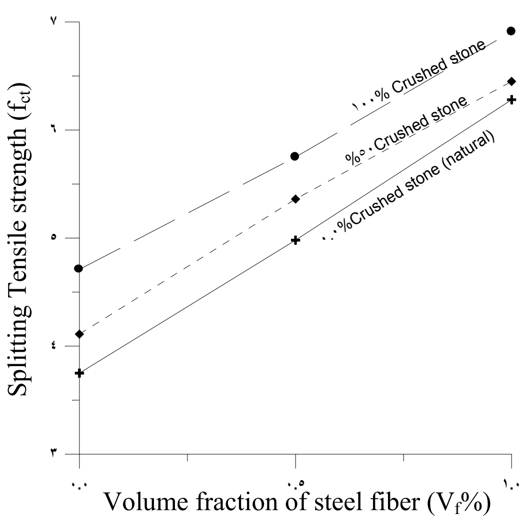
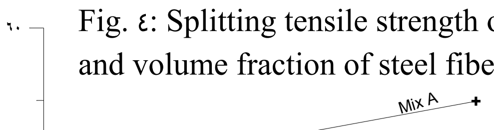
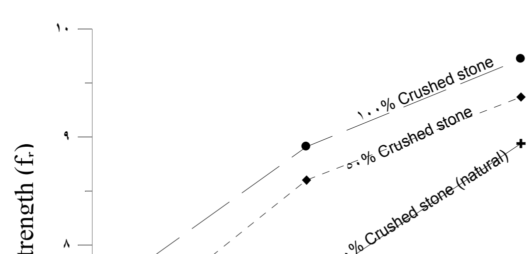



Fig. ٤: Splitting tensile strength of concrete and volume fraction of steel fiber relationship



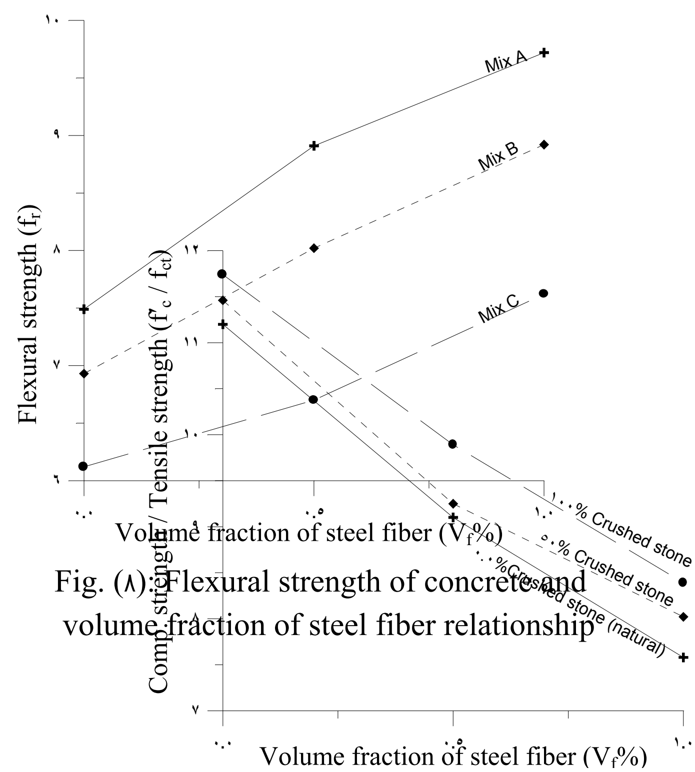



Fig. (٨): Flexural strength of concrete and volume fraction of steel fiber relationship

Fig. (٩): $f'_c$ / $f_{ct}$ & $V_f$% relationship for different percentages of crushed stone content

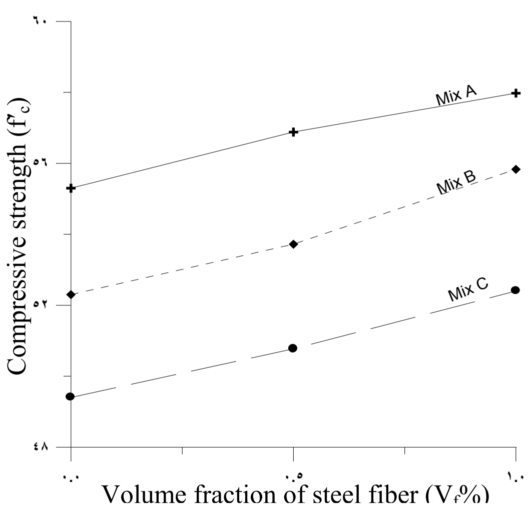



Fig.(٦): Compressive strength of concrete and volume fraction of steel fiber relationship

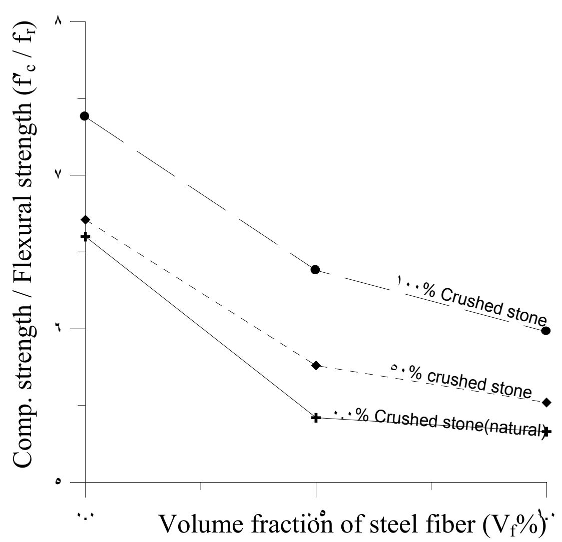
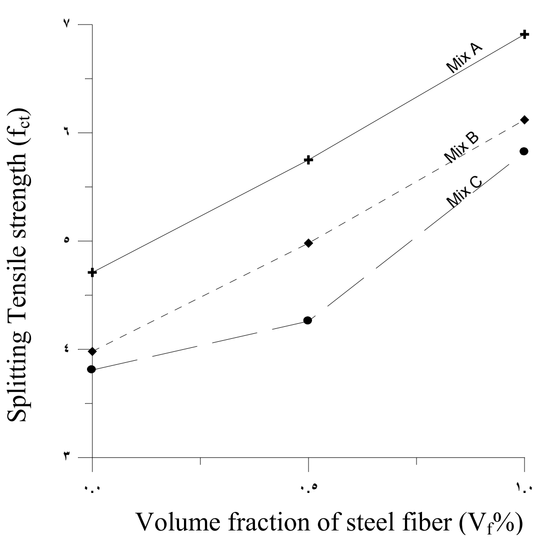



Fig. (١٠): $f'_c$ / $f_r$ & $V_f$% relationship for different percentages of crushed stone content



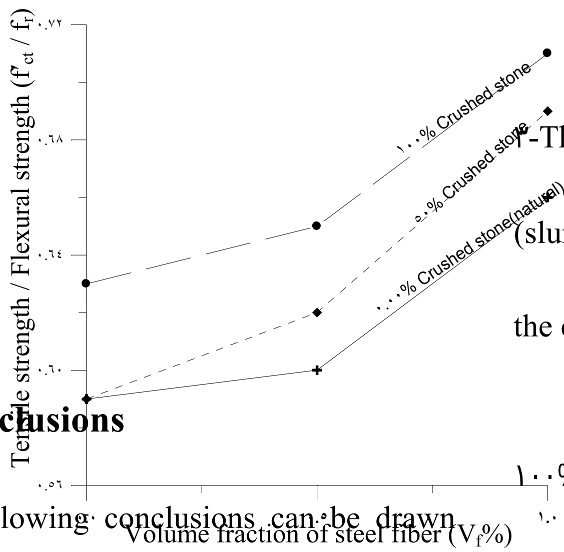



Fig. (١١): $f_{ct}/f_r$ & $V_f$% relationship for different percentages of crushed stone content

## Conclusions

The following conclusions can be drawn from the results of this investigation.

١- The compressive, tensile and flexural strengths of high-strength concrete are improved by ١٣.٣%, ٦٧.٥% and ٤٠.٦% at increasing the volume fraction of steel fiber by ١%.

٢-By replacing the natural gravel by crushed stone, the compressive, tensile and flexural strengths of high-strength fibrous concrete are increased by ٤.٨%, ٤٦.٧% and ٢٩.٨% respectively.

٣-The workability of fresh concrete (slump value) decreased by ٢٩% when the crushed stone content increased by ١٠٠% for mix A. Also the workability decreased by ٣٦%, ٣٨.٨% and ٥٠% by increasing the volume fraction of steel fiber by ١% for mixes A, B and C respectively.

٤- The $f'_c/f_{ct}$ and $f'_c/f_r$ ratios decreased by increasing volume fraction of steel fiber, while the $f_{ct}$ / $f_r$ ratio is increased, because of the different mechanisms of failure in all three cases.

٥- The ACI-Code formulas for computing splitting tensile strength ($f_{ct}$) and modulus of rupture ($f_r$) can not be apply for HSFC. However, it can be concrete.

used for crushed stone high-strength

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## References


١- ACI Committee ٣٦٣; "*State of the Art Report on High-Strength Concrete.*" ACI Manual of Concrete Practice١٩٩٦; Part ١.

٢- Faroug, F., Szwabowski, J. and Wild, S.; "*Influence of Superplastisizers on Workability of Concrete.*", Journal of Materials in Civil Engineering, **Vol. ٢, No. ٢**, May, ١٩٩٩, PP ١٥١-١٥٧.

٣- ACI Committee ٥٤٤; "*State of the Art Report on Steel Fiber Reinforced Concrete.*" ACI Manual of Concrete Practice١٩٩٦; Part ٥.

٤- Romualdi, J.P. and Batson, G.B.; "*Mechanics of Crack Arrest in Concrete.*" Journal of Eng. Mech., Div. Am. Soc. Civ. Eng. **Vol.٨٩, No. EM٣**, June ١٩٦٣; PP ١٤٧-١٦٨.

٥- Hassan, A.A.; "*Effect of Crushed Stone on the ultimate strength and Behaviour of Reinforced Concrete Beams.*" M.Sc. Thesis, University of Salahaddin, ١٩٨٨.

٦- Al-Baladawi, T.A. "*Investigation of the Use of Crushed Boulder Sand in Concrete.*" M.Sc Thesis, University of Baghdad, ١٩٨٠.

٧- Mahawish, A.H., "*Investigation of the Use of Crushed Boulder Aggregate in Concrete*." M.Sc Thesis, University of Baghdad, ١٩٨٠.

٨- Aziz, O.Q., and Saeed, J.A., "*Strength of Crushed Stone Fibrous Concrete.*" Dirasat, Natural and Engineering Sciences, **Vol. ٢٥, No.١**, ١٩٩٦.PP ٨-١٤

٩- Rao, D.S., and Kumar, V.G., "*Investigations on Concrete with Stone Crusher Dust as Fine Aggregate.*" www.icjonline.com/August٢٠٠٤.htm

١٠- Karkrija, C.B., and Kaushik, M.B., "*Tensile Strength of Steel Fiber Reinforced Concrete.*" Indian Concrete Journal, **Vol. ٩**, ١٩٨٠, PP١٨٤-١٨٨.

١١- Ramzi, B., "*Influence of Fiber Content on Reinforced Concrete Members.*" Eng. and Technology Journal, **Vol. ١٢, No. ٩**, ١٩٩٣.

١٢- Ezeldin, A.S., and Balaguru, P.N., "*Normal-and High-Strength Fiber Reinforced Concrete Under Compression.*" Journal of Materials in Civil Engineering, ASCE, **Vol.٤, No.٤**, ١٩٩٢, PP ٤١٥-٤٢٩.

١٣- Wafa, F.F.., and Ashour, S., A. "*Mechanical Properties of High-Strength Fiber Reinforced Concrete.*" ACI Materials Journal, **Vol. ٨٩, No. ٥,** Sep.-Oct., ١٩٩٢, PP ٤٤٩-٤٥٥.

١٤- Lok, T.S., and Xiao, J.R. "*Flexural Behaviour of SFRC: Testing and Modeling.*" Journal of Material in Civil Engineering, **Vol. ١١, No. ٤**, Nov. ١٩٩٩, PP ٣٣١-٣٣٩.

١٥- Lok, T.S., and Jin, S.P., "*Flexural Behaviour of Steel Fiber Reinforced Concrete.*" Journal of Material in Civil Engineering, **Vol. ١٠, No. ٢**, May ١٩٩٨, PP ٨٦-٩٧.

١٦- Ashour, S.A., and Wafa, F.F., "*Flexural Behaviour of High-Strength Fiber Reinforced Concrete Beams.*"; ACI Structural Journal, **Vol. ٩٠, No. ٣**, May-June, ١٩٩٣, PP ٢٧٩-٢٨٧.

# مقاومة خرسانة عالية ا قاومة و ا عززة بالألياف الفولاذية وال نوي على ا جر ا كسر


شل سعيد قادر

مدرس مساعد/ا عهد التق دهوك



**ا لاصة:** هذا البحث دراسة تأث النسب ا جمية للألياف الفولاذية و كمية ا جر ا كسر على خواص خرسانة عالية ا قاومة حالات الضغط، الشد و الانثناء. وقد أظهرت النتائج بأن زيادة الألياف الفولاذية بنسبة حجمية ١%، تؤدي ا زيادة مقاومة الضغط، الشد و الانثناء بنسب (١٣.٣، ٦٧.٥ و ٤٠.٦ %) على التوا عند استعمال ا صى الطبيعي، و عند استعمال حجر ا كسر بنسب (٤.٨، ٤٦.٧ و ٢٩.٨ %). و النتيجة فان بالإمكان استخدام ا جر ا كسر بدلا من ا صى الطبيعي إنتاج خرسانة عالية ا قاومة الأماكن ال تعا من عدم توفر ا صى الطبيعي.


# ڕەوشتی کۆنکریتی بەهێز و دارێژراو بە ریشاڵی ئاسنین


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**کورتە:** لەم لێکۆڵینەوەیەدا کارتێکردنی ڕێژەی قەبارەیی ریشاڵی ئاسنین و بری بەردی شکاو لەسەر بەرهەڵستی کۆنکریت لە رووی (پەستاندن، راکێشان و چەمانەوە) روون کراوەتەوە. ئەنجامەکان دەریان خست کە زیادکردنی ریشاڵی ئاسنین بە ڕێژەی ١٪ دەبێتە هۆی زیادبوونی بەرگریپەستان، راکێشان و چەمانەوە بەرێژەی (١٣,٣، ٦٧,٥ و٤٠,٦٪)بەدوایەیەکدا بۆ چەوی‌سروشتی و (٤,٨، ٤٦,٧ و ٢٩,٨٪) بۆ چەوی بەردی شکاو. وەلەکۆتاییدا دەتوانرێت بەردی شکاو لە بری چەو بەکاربهێنرێت لە کۆنکرێتی بەهێزدا بە تایبەتی لەو شوێنانەی کە چەوی سروشتیان کەمە.