

MECHANICAL PROPERTIES OF CONCRETE INCORPORATED BFS AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT: - The present research aims at developing special types of concrete known as Blast Furnace Slag Concrete by partial replacement of cement by Blast Furnace Slag (BFS) at different weight percentages (5, 15, 20, 30, and 40) %.

The weight percentage was studied as it effects the physical and mechanical properties (density, compressive strength, flexure strength, dynamic modulus of elasticity, and quality factor).

The results indicate that the density of concrete increases with BFS content increment, BFS enhanced the compressive strength, flexural strength, and the dynamic modulus of elasticity.

On the other hand the quality factor is reduced with increasing slag addition. In general, the results indicated that the best result was observed at a replacement value of about 20% by weight.

Key Words: Slag concrete, dynamic properties, Nondestructive test, Compressive strength of concrete, Quality factor.

1. INTRODUCTION

Concrete is, in the broadest sense, an artificial stone that is cast in place in plastic condition. Its essential ingredients are cement and water to react with each other chemically to form another material having useful strength⁽¹⁾. To increase the volume, and stability of artificial stone produced from a prescribed amount of cement it is customary to add inert filler material known as "aggregate".

Blast furnace slag is a by – product obtained from the manufacturing of pig iron in the blast Furnace and is formed by the combination of earthy constituents of iron ore with limestone flux . When the molten slag is swiftly quenched in water, or cooled with powerful water jets, it forms a fine, granular, almost fully non -Crystalline, glassy form as granulated slag, having latent hydraulic properties^(2, 3, and 4).

Slag is often used in concrete in combination with Portland Cement as part of blended cement . Slag react with water to produce cementitious properties. Concrete containing BFS develops strength over long period, leading to reduced permeability and better *durability*^(5,6).

The reactivity of blast furnace slag (BFS) depends on the properties of slag , which vary with the source of slag , type of raw material used , method, and rate of cooling^(5,6) .

In most previous researches , the (BFS) were used with partial replacement range between (20 – 40) % by weight of cement, to produce blast furnace slag concrete but the optimum percentage of slag which gives suitable properties of concrete was not studied⁽⁷⁾. The aim of the present study is to investigate the dynamic and static mechanical behaviors of concrete by the addition of slag, reaching a maximum control for this behavior

2 – Experimental Program:

2.1 Materials

a – Cement

Type (1) ordinary Portland cement was used, the chemical and physical properties are conformable with the requirements of the Iraqi Organization Standard IQS. No. 5, 1984⁽⁸⁾. The chemical composition and physical characteristics of cement are given in table (1), and table (2).

b - Fine Aggregates

The fine aggregates used was natural sand of 4.75 maximum size complying with the Iraqi Organization Standard IOS (45), the sieve analysis is given in table (3).

c - Coarse Aggregates

Crushed gravel with (12.5 mm) maximum size was used, it conforms with IOS No. 45⁽⁹⁾. The grading was prepared in the laboratory. The sieve analysis is given in table (4).

d - Blast Furnace Slag (BFS)

Ground steel slag, which is a by product of local furnace at steel melting, was used as a partial replacement for ordinary Portland Cement. The slag was brought as a large lump from Basrah Steel and Plant. The lumps were grounded to produce a powder with fineness of 580 m²/kg. The grinding was done in the National Center for Construction Laboratories and Research. The used slag conforms with the requirements of B. S 6699:1986. The chemical composition of slag is given in table (5).

2.2 Mix Proportions

Six groups of mixtures were used in this research with the same mix proportion (1: 1.54: 1.85) (cement: sand: gravel) and water cement ratio was 0.45 to give a slump of (60) mm. Mix design is made in accordance with building design established method. The first Mix (Ro), concrete was made using ordinary Portland cement only (considered as a control mix). While in the other mixtures, five proportions (5, 15, 20, 30 and 40%) by weight of the ordinary Portland Cement were replaced by blast- furnace slag (BFS). The details of the six concrete mixtures are shown in table (6).

* W/p = water / powder = water / (cement + slag)

2.3 Preparation Test Specimens

The recommendation of C 192 – 88 of ASTM standard were followed for preparing the concrete mixture⁽¹⁰⁾

The materials were proportioned by weight and mixed thoroughly using horizontal pan type mixer. For the mixtures incorporating slag, the different cementation materials were thoroughly blended before being added to the concrete.

Concrete cubes of 100x100x100 mm were used for density and compressive strength testing and prisms of (100 x 100 x 400) mm were used to measure flexural strength, dynamic modulus of elasticity and quality factor.

All specimens were cast in steel molds in three layers for cube and two layers for prism each layer was compacted by means of vibrating table. Then the specimens were kept in their molds at the laboratory for 24 hours. After that the specimens were remolded carefully and immersed in water tank to be cured for 28 days. Then the specimens were stripped out from the water tank and the tests were carried out.

2.4 Experimental

a – Workability of Slag Concrete

The workability of all concrete mixtures was determined by slump test in accordance with the procedure described in ASTM C143 – 2005⁽¹¹⁾.

b – Density

The test was carried out on the same specimens of the compressive strength test (100) mm cube. After 28 days of moist curing, the specimens were left one hour for drying in the laboratory and they were weighted using a digital electronic balance reading accurately to 0.1 g. The density was calculated by dividing the mass by the volume of the cube.

c - Compressive Strength

Compressive strength was determined using (100x100x 100) mm cubes according to B. S. 1881 part 116⁽¹²⁾. The average compressive strength of three cubes was recorded for 28 days age.

d - Flexural Strength

(100 x 100 x 400) mm concrete prisms were used for this test. Two point load test was carried out according to ASTM C78 – 94⁽¹³⁾ Average modulus of rupture of three prisms was recorded for 28 days age.

e - Dynamic Modulus of Elasticity (E_d)

Measurements were performed on laboratory specimens (100 x 100 x 400) mm prisms subjected to longitudinal vibration at their natural frequency, corresponding to ASTM C 215-85⁽¹⁴⁾. The Dynamic Modulus of Elasticity (E_d) is calculated by the following equation:

$$E_d = 4 \times n^2 \times L^2 \times w \times 10^{-12} \dots\dots\dots(1)$$

Where

Ed: Dynamic Modulus of Elasticity, GPa

L: length of the specimens, mm

n: natural frequency of the fundamental mode of longitudinal vibration of the specimens , HZ

w. density of the specimens , kg /m³.

F - Quality Factor (Q)

The Q – value is calculated from knowledge of the fundamental resonant frequency and frequencies on either side of the resonant frequency where the amplitude of vibration drops to 0.707 of the maximum amplitude, Fig (1). The quality factor (Q) is determined using prism (100 x 100 x 400) mm and calculated from the band width as follows⁽¹⁵⁾

$$Q = \frac{n_0}{n_1 - n_2} \dots\dots\dots (2)$$

Where

n₀: fundamental resonant frequency

n₁, n₂: frequencies on either side of the resonant frequency

3 – Results and Discussion**3 – 1 Workability**

For the given water – cement ratio of 0 .45, the controlled cement concrete mixture (Ro) yielded a slump of (60 mm), whereas the other concrete mixtures containing slag cement exhibited workability (63 – 86) mm as shown in Fig. (2). The addition of Blast Furnace Slag (PFS) has improved the workability. Due to the several factors related to increased paste cohesiveness, low initial water absorption of slag⁽²⁾,

the slag with same fineness of ordinary Portland cement (OPC) , the texture of slag surface tends to be much smoother than that of (OPC) Also the specific gravity of the slag is lower than that of (OPC) (2.9 compared to 3.15), and the replacement on a mass – to – mass will lead to an enhanced powder volume with a reduced water demand for constant workability⁽⁷⁾.

3 – 2 Density

Fig. (3) Shows the values of density at 28th days for all concrete mixes, where obviously shown that addition of (PFS) enhances the bulk density of concrete.

This density increase may be due to the fact that , silicate in slag cement combine with the calcium hydroxide (CH) which is the byproduct of hydration between cement and water and form additional calcium – silicate – hydrate (CSH) . This in turn leads to a denser, harder cementations paste, which increases ultimate strength as compared to 100% Portland cement systems^(2,4)

3. 3 Compressive Strength

The test results of compressive strength for all mixtures: of concrete at 28 days immersion are plotted in Fig (4). They show that the concrete incorporating (5 and 15) % slag has a slight increase in compressive strength (4. 3 and 8.4) %, respectively compared with control sample. Further addition of slag (20) % by weight of cement, exhibited significant increase in the compressive strength reaching about 35.8% as compared with their control concrete. This increase in the three mixtures (R5, R15, and R20,) may be attributed to the fact that when mixed water is added to the PC-slag, Portland Cement component begins to hydrate first. Although there is also a small amount of immediate reaction of slag which releases calcium and aluminum ions into solution ^(4, 16). The slag then reacts with alkali hydroxide followed by a reaction with the calcium hydroxide released by Portland cement, (CSH) would be formed ⁽¹⁶⁾ increasing the ultimate strength of concert. Those containing slag exceeding 20 weight percent, exhibited reduced compressive strength values, and similarity R30+R40 also exhibited slight reduction

This reduction in compressive strength may be due to the fact that, concrete with pozzolana such as slag, would gain strength very slowly and require longer period to cure. Because the addition of the pozzoolanic materials over 20% by weight of cement will retard the rate of strength development. The degree of retardation is dependent upon the amount and composition of both the pozzoolanic materials included and the cement ^(2, 4, and 7).

3 – 4 Flexural Strength

The Flexural strength measurements of various mixtures are shown in fig (5).

It is shown that, the addition of slag with percentage of (5,15and 20) % as a partial replacement of cement will enhance the flexural strength value of concrete. The percentage of increase for (R5, R15 and R20) concrete measured relative to their (R0) were (14, 26.3 and 48 40.5 and 29.9) %, respectively

After that, any addition of slag over 20% by weight of cement will decrease the flexural strength of concrete. Therefore, the flexural strength of concrete mixtures (R30 and R40) were (6.35 and 5.87) MPa, respectively compared with (R20) with (6.69) MPa. Even though, this mixture (R30 and R40) still have flexural strength greater than control concrete (R0). The higher flexural strength of slag concrete has also been reported by others ^(1,2,17,18,19). Mixture may be attributed to the greater quantity of crystallize ettringite in the paste of the slag concrete, as crystallization is found to favor higher flexural strength values. It may also be due to fact that stronger bonds in the cement/slag/ aggregate system initiated by the shape and surface texture of the slag particles. Similar behavior has also been reported by lea ⁽²⁰⁾ for burnt clay concrete

3 – 5 Dynamic Modulus of Elasticity (E_d)

Fig. (6) Shows values of the dynamic modulus of elasticity (E_d) of all concrete mixtures containing different percentage of slag. It is obvious that (E_d -) of slag concrete are higher than the control concrete. They increase with increasing percentage of slag up to about (20%), after which the amount of increase in (E_d) declines for the mixture containing (30% and 40%) slag. Sivasundarm, And Molhotra reported that the 28 days(E_d) values of the high – volume (50 – 75) % slag concrete were higher than that of control concrete. This may be due to the modification of the properties of the slag hydrates compared with those of the control concrete

3 – 6 Quality Factor (Q)

Fig (7) shows the variation of quality factor (Q) for all mixes of concrete. It is obvious that the addition of slag reduces the (Q) values of concrete. Since, the quality factor somewhat represents the ability of a medium to dissipate energy or absorb it. Therefore, as the percentage of slag increases the material tends to lose its ability to dissipate energy, because of the enhanced density of slag concrete as compared to controlled concrete.

4 – Conclusions

- 1 – In general, the incorporation of (BFS) as a partial replacement by weight of cement will improve the fresh, physical, and mechanical properties of concrete.
- 2 – The percentage of slag in concrete greatly modified the state of elasticity of the concrete.
- 3 – The addition of (BFS) as partial replacement by weight of cement will enhance the workability of concrete while maintaining equal water / cementitious materials ratio.
- 4 – The density of slag concrete increase with increasing the percentage of (BFS). The percentage of increase in density was between (0.5 – 9.1) % when the percentage of slag was between (5 – 40) % by weight of cement
- 5 – At 28 days moist curing ,the addition of (5 – 20) % of slag as a partial replacement of cement will increase the compressive strength flexural strength and dynamic modulus of elasticity of concrete and the maximum increase was (35.8 ,48 and 17.6) %when using (20) % slag . After that increase in slag, the mechanical properties of concrete with reduce.
- 6 – The optimum percentage of slag was 20% by weight of cement. This percentage gives us suitable properties for slag concrete in this research.

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Table (1): percentage oxide composition of cement

Oxide	Content %	Limit of Iraqi Specification IOS No.5
SiO ₂	22.0	—
CaO	61.1	—
MgO	2.21	≤ 5
Fe ₂ O ₃	2.47	—
Al ₂ O ₃	5.7	—
SO ₃	2.5	≤ 2.8
Lose on ignition	2.5	≤ 4%
Insoluble residue	1.0	≤ 1.5
L.S.F	0.85	0.66 – 1.02

Table (2): physical characteristics of cement

Physical properties	Test result	Limit of Iraqi specification IOS No.45
Fineness Blaine method Cm ² /g	2820	≥2300
Setting time h:min initial setting final setting	1:35 2:40	≥ 45 min ≤ 10 hrs
Compressive strength (N/mm ²) 3 day 7 day Soundness %	17.47 25.25 0.24	≥ 15 N/mm ² ≥ 23 N/mm ² ≤ 0.8

Table (3): Grading of fine aggregate

Sieve Size mm	Cumulative percentage passing	Limit of Iraqi specification IOS No.45, Zone 3
10	100	100
4.75	99	90 - 100
2.36	97	85 - 100
1.18	91	75 - 100
0.6	79	60 - 79
0.3	47	12 - 40
0.15	6	0 - 10

Table (4): Grading of coarse aggregate

Sieve Size mm	Cumulative Percentage Passing	ASTM C-33
12.5	100	100
9.5	85	85 - 100
4.75	12	10 - 30
2.36	5	0 - 10
1.18	2	0 - 5

Table (5): Chemical Composition of Blast Furnace Slag (Parentage by weight).

Slag Type	CaO	SiO ₂	Al ₂ O ₂	Fe ₂ O ₃	SO ₃	MgO	Insoluble residue
BFS	24	15	1.16	15.24	-	9.32	34

Table (6): details of mix design of slag concrete

Mix symbol	Cement kg/m ³	Slag %	Slag kg/m ³	Gravel kg/m ³	Sand kg/m ³	Water L/m ³	W/p* ratio
R0	478	0	0	885	737	215	0.45
R5	454.1	5	23.9	885	737	215	0.45
R15	406.3	15	71.7	885	737	215	0.45
R20	382.4	20	95.6	885	737	215	0.45
R30	334.6	30	143.4	885	737	215	0.45
R40	286.8	40	191.2	885	737	215	0.45

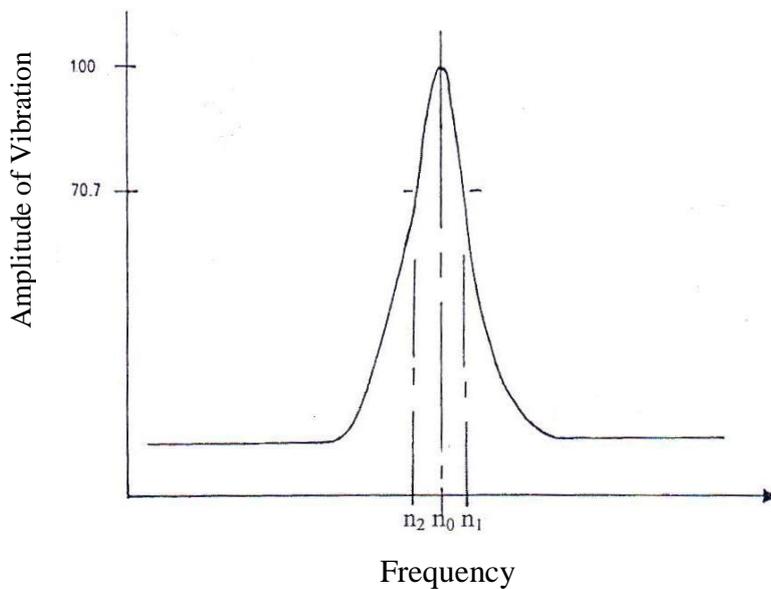


Fig. (1): Typical curve of amplitude of vibration with frequency

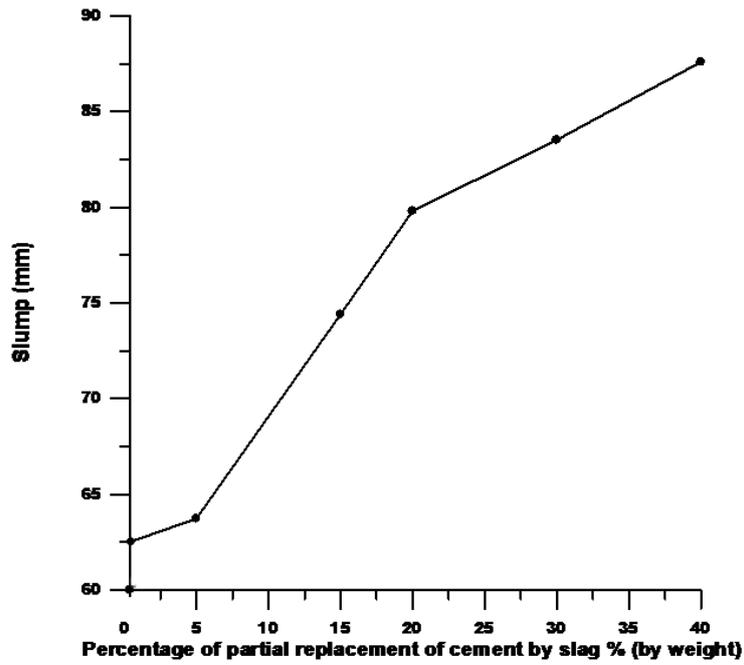


Fig. (2): The effect of slag as a partial replacement of cement on the workability of concrete

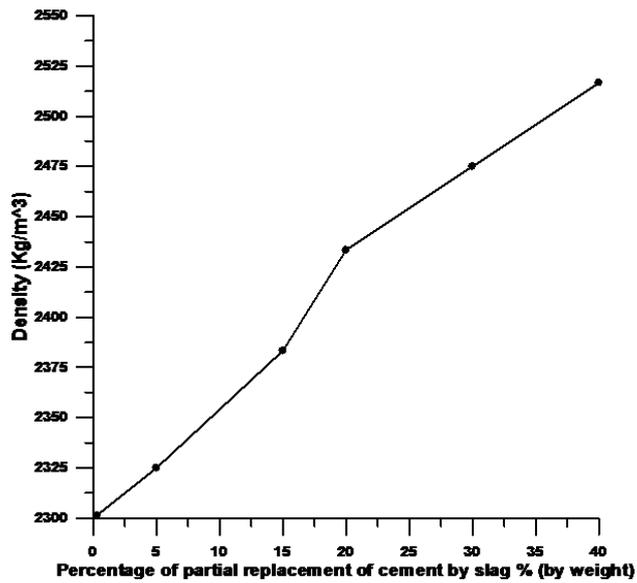


Fig. (3): The relationship between the density at (28 day) and the percentage of the replacement of cement by slag

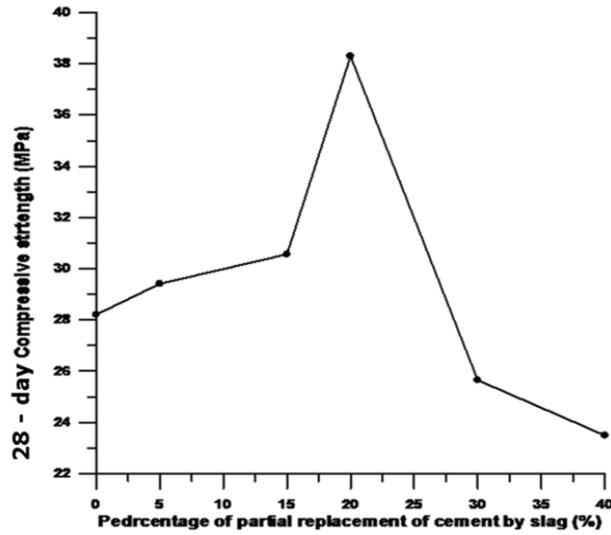


Fig. (4): The effect of slag as a partial replacement of cement on the compressive strength of concrete

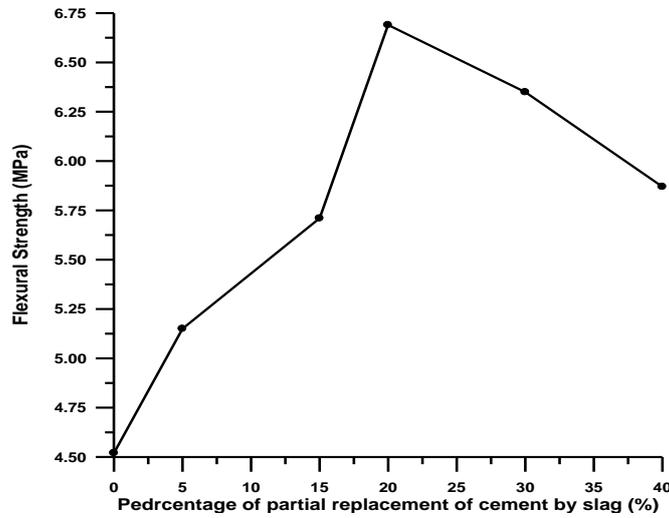


Fig. (5): The effect of slag as a partial replacement of cement on the flexural strength of concrete

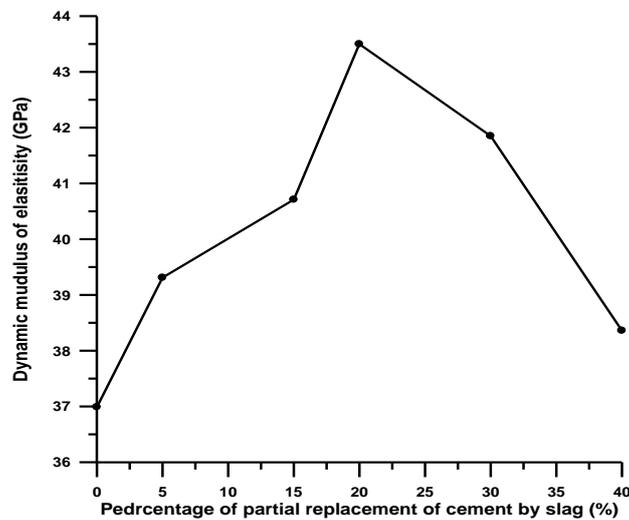


Fig. (6): Effect of partial replacement of slag on the modulus of elasticity of concrete

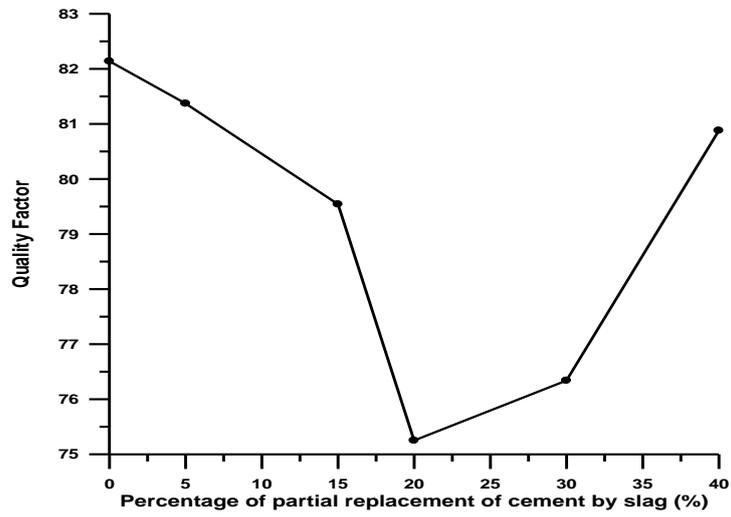


Fig. (7): Effect of partial replacement of slag on the modulus of elasticity of concrete

الخلاصة

يهدف البحث الى تطوير أنواع خاصة من الخرسانة تعرف بخرسانة خبث الافران العالية و ذلك عن طريق احلال جزئي بخبث الافران محل السمنت و بنسب وزنية مختلفة (5, 15, 20, 30, 40)%.

أثرت النسب الوزنية على الخصائص الفيزيائية و الميكانيكية للخرسانة (الكثافة , مقاومة الانضغاط , مقاومة الانتشاء , معامل المرونة الديناميكي , فضلاً عن عامل النوعية). أشارت النتائج بأن كثافة الخرسانة تزداد بزيادة كمية خبث الافران , كذلك فأن الخبث يقوي و يدعم مقاومة الانضغاط , مقاومة الانتشاء فضلاً عن معامل يونك الديناميكي. من ناحية اخرى فأن عامل النوعية يتناقص بزيادة اضافة الخبث. بصورة عامة إشارة النتائج الى أن كمية الخبث المثلى كانت بقيمة 20% من وزن السمنت.

الكلمات المفتاحية: خرسانة الخبث , الخصائص الديناميكية , مقاومة الانضغاط للكونكريت , الفحص الغير اتلافي عامل النوعية.