Effect of Partial Replacement of Sand with Limestone Filler on Some Properties of Normal Concrete

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Abstract

In recent years, there is a growing interest in the use of crushed sand obtained from limestone quarries in some countries where river sand is not widely available. Besides, the demand for aggregates to produce concrete is still high while natural resources decrease. The fines content in limestone is usually high (particles with a size of 0.15-0.7 mm) which can affect concrete properties in an either positive or negative way. Studies on aggregate containing fine materials are vitally important. However, little work has been done so far on the effect of fines in crushed sand on the properties of concrete.

This paper examines the influence of limestone filler in sand on concrete properties, which include workability of fresh concrete (slump test method), compressive and tensile strength, unit weight, and ultrasonic pulse velocity. Six concrete mixtures containing different ratios of limestone filler (0, 10, 20, 30, 40, 50) % sand replacement were used while maintaining a constant water/cement ratio. The results proved that limestone filler replacing sand up to 20% without adversely affecting concrete strength.

Key words: limestone filler; crushed sand.

تأثير مسحوق حجر الكلس كبديل جزئي من الرمل على بعض خصائص الخرسانة الاعتيادية

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الخلاصة

في السنوات الأخيرة، أصبح هنالك اهتمام متزايد من قبل بعض البلدان لاستخدام مسحوق الرمل الناتج من سحق حجر الكلس حيث الرمل النهري غير متوفرَ بشكل واسع، إضافة إلى الطلب المستمر والمتزايد بمستوى عالي على الركام لأنتاج الخرسانة بينما مصادر الطبيعة في تناقص مستمر. عادة ما تكون نسبة المواد الناعمة في مسحوق حجر الكلس عالية (جزيئات يتراوح مقاسها بين 0.15-0.07 ملم) و يمكن أن تؤثر على خصائص الخرسانة بصورة ايجابية أو سلبية.

يمكن القول ان الدراسات حول الركام الحاوي على مواد ناعمة إجمالاً مهمة بشكل حيوي ومع ذلك فالقليل من البحوث تناولت تأثير المواد الناعمة في مسحوق الرمل على خصائص الخرسانة.

تضمن البحث تأثير مسحوق حجر الكلس في الرمل على خصائص الخرسانة التي تضمنت فحص قابلية التشغيل للخرسانة الطرية (فحص الهطول) ومقاومتي الانضغاط والشد الانشطاري ووحدة الوزن وسرعة الموجات فوق الصوتية من خلال صب ستة مزجات خرسانية ذات نسب مختلفة لمسحوق حجر الكلس تضمنت (0،10،20،30،40،50)% مستبدلة من الرمل مع الحفاظ على نسبة الماء إلى الإسمنت ثابتة. أثبتت النتائج انه يمكن استبدال الرمل بمسحوق حجر الكلس لغاية نسبة 20% وبدون أي تأثير سلبي على المقاومة.

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Introduction

In recent years, there is a growing interest in the use of crushed sand obtained from limestone quarries in some countries where river sand is not widely available. Besides, the demand for aggregates to produce concrete is still high while natural resources decrease.

A large amount of material in the size of filler is produced during the course of crushing the weak limestone, in particular, which may well be used as an aggregate. The application of these materials is beneficial to improving the concrete so as to decrease air voids [1].

For many years limestone has been increasingly used in concrete as a coarse aggregate, filler or as a main cement constituent [2]. It is applied in high performance concrete as well as in normal or low performance concrete [3,4,5]. Compared to plain concrete with the same w/c ratio and cement type, concrete with a high limestone filler content with suitable particle size distribution (PSD) possesses generally improved strength characteristics.

A certain amount of fines is helpful in concrete for improving cohesiveness and preventing bleeding. However, excessive quantities of fines tend to increase the water demand and tend to impair the aggregate-cement paste bond. Crushed rock acts as filler and helps to reduce the total voids content in concrete. Consequently, this contributes to improve the quality of concrete. Limestone crusher dust is used as a filler material for cement or aggregates and might have some beneficial effects on concrete depending on the percentage replacement and chemical composition of dust [6].

The effect of inclusion of limestone filler in cement on fresh and hardened mortar and concrete has been a major research topic for many years [2], but little work has been done so far on the effect of limestone filler in sand on the properties of concrete. This paper reports the results of an experimental investigation on the influence of limestone filler as partial replacement of sand on concrete properties.

Aim of study

Crushed limestone is used as a coarse aggregate or a filler material for cement and aggregates, it might have some beneficial effects on concrete depending on the percentage replacement, so the objective of the investigation subject of this paper is to study quality criteria of concrete made of sand with partial replacement of limestone filler with locally available material. To find out the extent of improvement in concrete properties for different amounts of limestone filler, proportion of (0, 10, 20, 30, 40, 50)% replacement are considered, concrete properties include workability (slump test) of fresh concrete, unit weight, ultrasonic pulse velocity, compressive and splitting tensile strength of hardened concrete are studied.

Experimental details

Materials

Cement

The cement used in this study was obtained from Senjar Cement Plant. The chemical compositions and physical properties, of the cement used, were determined according to Iraqi Standard (IQS 5 – 1984)[7] are given in Table(1).

Limestone filler

Crushed limestone filler retained on the sieve No. 200 was used with specific gravity of 2.61. The chemical compositions was determined and presented in Table (2).

Table(1): Properties of cement

Chemical analysis of cement*

Oxide composition	SiO_2	Fe_2O_3	Al_2O3	CaO	MgO	SO_3
Content (%)	21.50	2.68	6.2	62.76	2. 80	2.27
IQS No5-1984 requirements(%)	17-25	0.5-6.0	3-8	60-67	Max 5	Max 2.8

Mineralogical components	C3S	C2S	C3A	C4AF
Content (%)	40.93	28.78	12.06	7.89
IQS No5-1984 requirements(%)	31.3-41.05	28.61-37.9	11.96-12.3	7.72-8.02

Mechanical properties

Age (days)	Compressive strength (MPa)		Tensile strength (MPa)	
	Cement used	IQS No5-1984 requirements	Cement used	IQS No5-1984 requirements
3	19.2	Not less than 16	1.72	Not less than 1.6
7	26.1	Not less than 24	2.55	Not less than 2.4

Physical properties

Setting time (hrs)	Initial		Final	
	Cement used	IQS No5-1984 requirements	Cement used	IQS No5-1984 requirements
	1.75	Not less than 45 min	3.50	Not more than 10 hrs

* Data are given by the manufacturer.

Table (2):Chemical analysis of limestone filler*

Oxide Composition	SiO_2	Fe_2O_3	Al_2O3	CaO	MgO	SO_3	Losses
Content (%)	1.81	0.27	0.27	50.28	1. 53	0.25	45.59

* Analysis done in Badush Cement Plant.

Aggregate

Coarse aggregate

River rounded gravel comply with the (B.S 882:1992)[8] was used as a coarse aggregate with max aggregate size 12.5 mm, Fig.(1) shows particle size distribution of coarse aggregate.

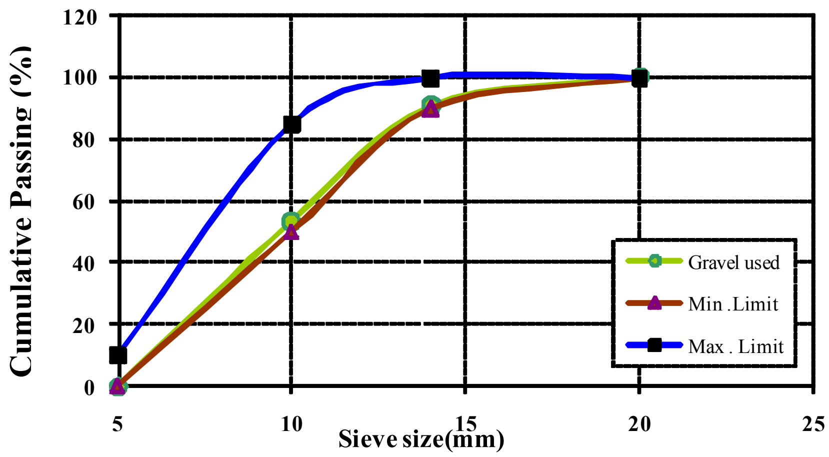

Fig.(1): Particle size distribution of coarse aggregate

Fine aggregate

River sand was used as fine aggregate with fineness modulus of 2.81, the results of the sieve analysis that was carried out in accordance with the (B.S. 882:1992)[8] for the fine aggregate for sand with partial replacement of limestone filler content include (0, 10, 20, 30, 40, 50)% showed that its grading fits within the limits set out in B.S. 882 , Fig. (2) shows the particle size distribution of fine aggregate (sand with percentage partial replacement of limestone filler).

Fineness modulus decrease with limestone filler amount from 2.81 (for the reference mix) down to 2.11 (for 50% limestone filler content) which represent about 25% decrease (Table (3)) despite this, the aggregate remains in conforming with BS standards.

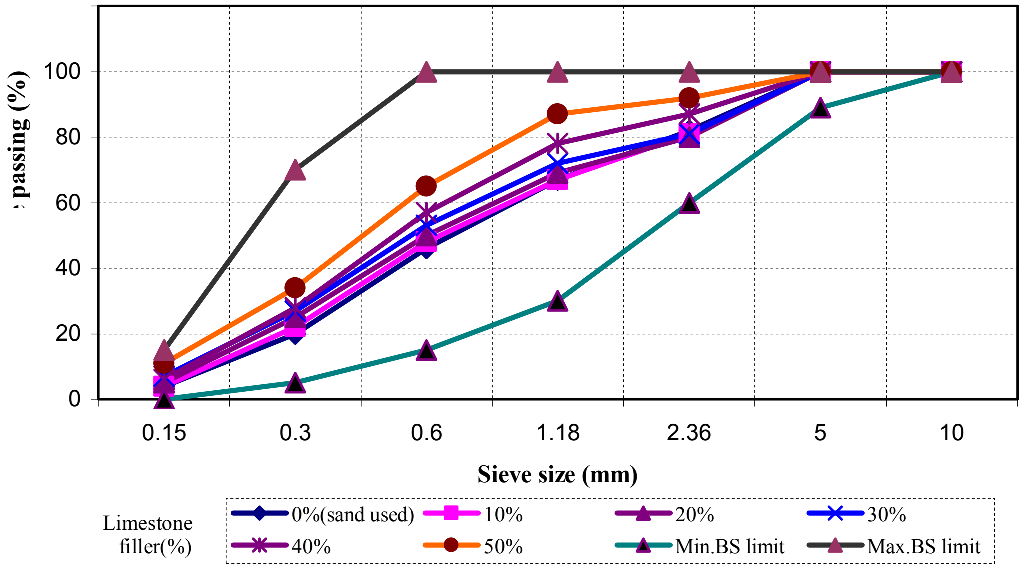

Fig.(2): Particle size distribution of fine aggregate(sand with percentage partial replacement of limestone filler)

Concrete mixes used in investigation

A total of six concrete mixtures were prepared. The first is a reference concrete mix (control mix), the remaining five mixtures with limestone filler of (10, 20, 30, 40, 50)% sand replacement. Water to cement ratio is constant at 0.57 throughout the test. The details of mixes composition are shown in Table (3).

Table (3): Composition of concrete mixtures

Filler addition (%)	Mix proportion (Kg/m^3)					sand with filler fineness modulus
	Cement content	Aggregate content		Limestone filler content	Water content	
		sand	gravel			
0	334	668	1202	0	190.4	2.81
10	334	601	1202	66.8	190.4	2.78
20	334	534	1202	133.6	190.4	2.71
30	334	468	1202	200.4	190.4	2.60
40	334	401	1202	267.2	190.4	2.44
50	334	334	1202	334	190.4	2.11

Specimen preparation and testing program

Aggregate, limestone filler and cement were mixed for one minute in a vertical rotating concrete flow mixer, mixing was continued for a further minute while water was added, slump test was done according to (ASTM C143)[9] to determine the concrete mixtures workability then unit weight test was done according to (ASTM C138)[10].

For each mixture, twelve cubical specimens of (100×100×100) mm for the compressive strength and three cylindrical specimens of (100 ϕ ×200) mm for the splitting tensile strength, were cast in steel moulds, a vibration table was used to consolidate the concrete. The specimens prepared were stored under cure conditions until the launch of the experiment. Compressive strength was determined for 3, 7, 14 and 28 days according to (BS 1881: Part 116)[11].Splitting tensile test and ultrasonic pulse velocity were determined at 28 days according to (ASTM C496) [12]and (ASTM C 597)[13] respectively .

Results and discussion

Influence of limestone filler content on the workability of fresh concrete

The slump test was used to measure workability as a function of limestone filler content for constant w/c ratio, the effect of limestone filler content on the slump is shown in Table (4) and Fig.(3) respectively. The slump value seems to decrease with higher percentage of limestone filler content, this result is related to the relatively high water absorption capability which is attributed mainly to the large specific surface of limestone filler [14].

Table (4): Slump values of concrete mixtures

Filler addition **(%)**	**0**	**10**	**20**	**30**	**40**	**50**
Slump(mm)	110	95	75	60	45	30

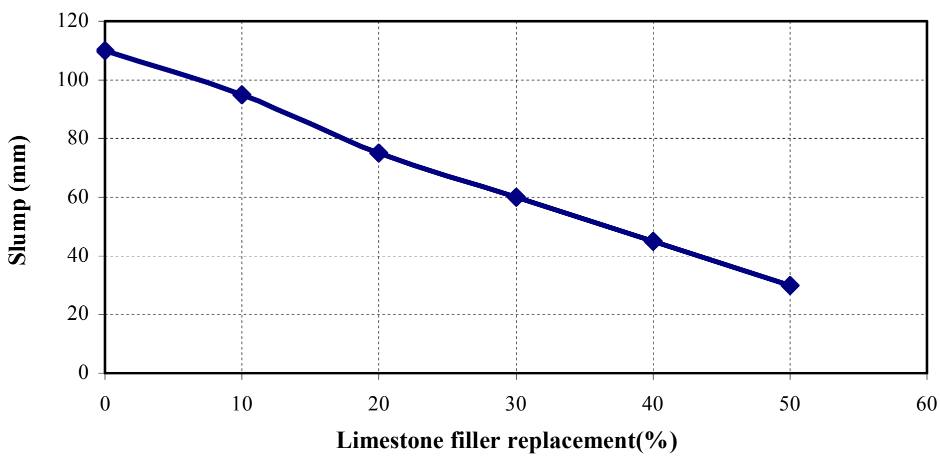

Fig.(3): The effect of percentage limestone filler replacement on the slump

Influence of the limestone filler content on the unit weight

Average values of three samples for unit weight are given in Table (5) and Fig.(4) respectively for each limestone filler proportion. It was observed that by increasing the limestone filler amount, the unit weight of the mix increases until a certain optimal value of limestone filler amount depending on the sand particle size distribution which represent 20% of sand replacement with limestone filler, at this amount of limestone filler the unit weight increased by 3.8% of its reference value, then a regular decrease for higher filler amount but still more than the unit weight of control mix; this is interpreted as fine particles of limestone filler filled spaces between grains of sand (before reaching maximum compactness), thereby increasing the mass volume of the mix. Once the voids were completely filled, fine particles then began to occupy the place of sand grains, which decreased the proportion of sand grains, and consequently the unit weight of the mix [15].

Table (5):Unit weight of concrete mixtures

Filler addition (%)	**0**	**10**	**20**	**30**	**40**	**50**
Unit weight (Kg/m^3)	2473	2492	2567	2533	2521	2519

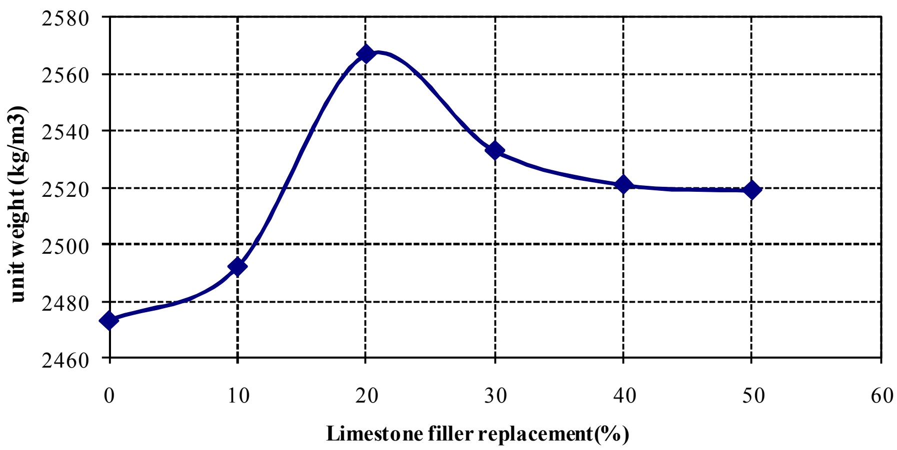

Fig.(4): The effect of percentage limestone filler replacement on the unit weight

Influence of the limestone filler content on the compressive strength

The compressive strength results of all concrete mixtures at the ages of 3, 7, 14 and 28 days age are illustrated in Table (6) and Fig.(5) respectively. The strength values are the average of three samples. At the different ages, there is a continuing improvement in the strength performance of the mixtures containing 10% and 20% limestone filler replacement, the compressive strength decrease when concrete contain (30,40 and 50)% limestone filler replacement with sand comparing to control mix.

Table (6):Compressive strength of concrete mixtures at ages of test days

Age (days)	***Filler addition* (%)**					
	0	**10%**	**20%**	**30%**	**40%**	**50%**
3	15.9	16.8	18.5	15.7	15.5	15.1
7	25.3	25.9	28.3	25.3	23.1	22.6
14	28.5	30.6	32.5	28	26.8	26
28	33.6	35.6	38.5	33.2	31.0	30.8

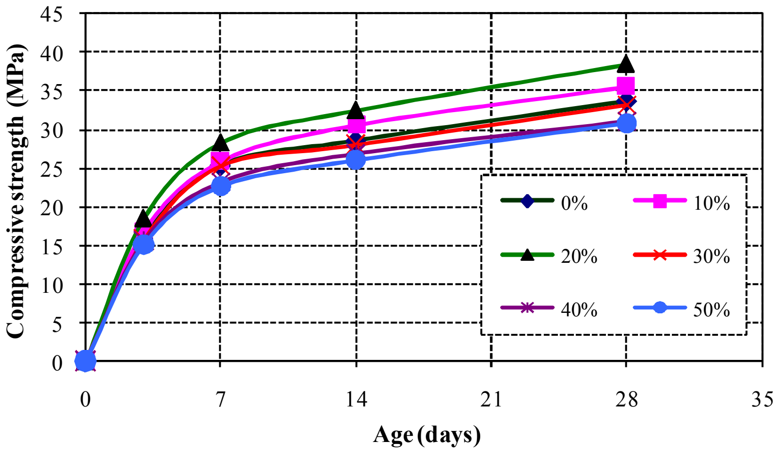

Fig.(5): The effect of percentage limestone filler replacement on the compressive strength at ages of test days

The development of relative compressive strength in concrete mixtures at ages of test days is shown in Fig.(6), relatively little effect of the addition of limestone filler on development of compressive strength of concrete mixtures at ages of test days corresponding to reference mix (without the filler).

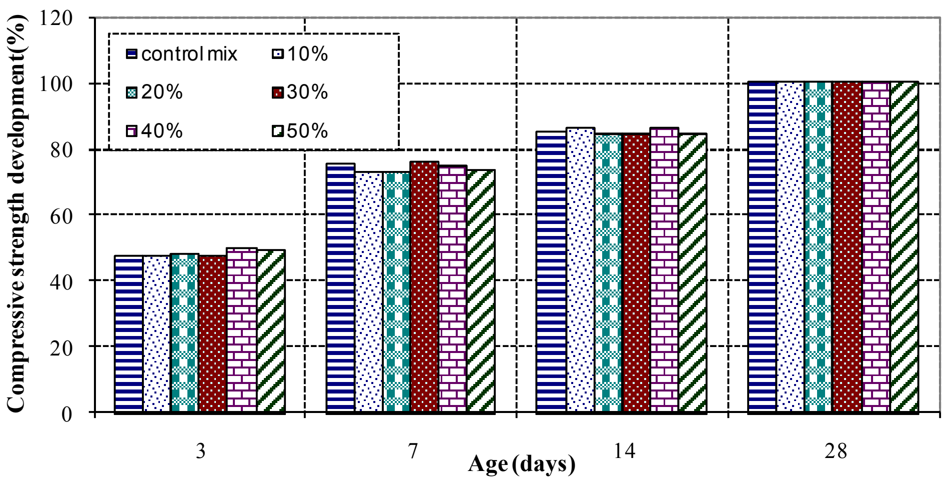

Fig.(6): Development of relative compressive strength in various concrete mixtures at different ages

Average values of three samples for compressive strength at 28 days age are summarized in Fig.(7) as a function of limestone filler proportion, it can be seen that as filler content increases, compressive strength also increases up to an optimal value (in this case at 20% limestone filler).

To show the effect of the addition of limestone filler on compressive strength of concrete, Fig.(8) shows the compressive strength with different addition of the filler as a percentage of the reference mix (without the filler).

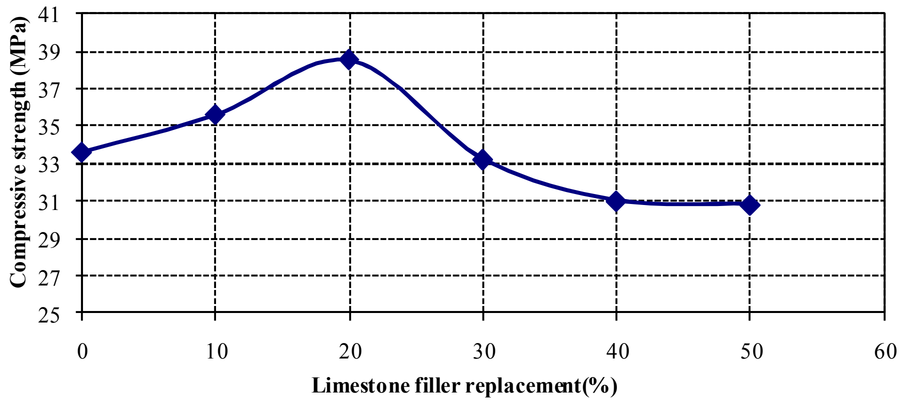

Fig.(7):The influence of percentage limestone filler replacement at 28 days age on the compressive strength

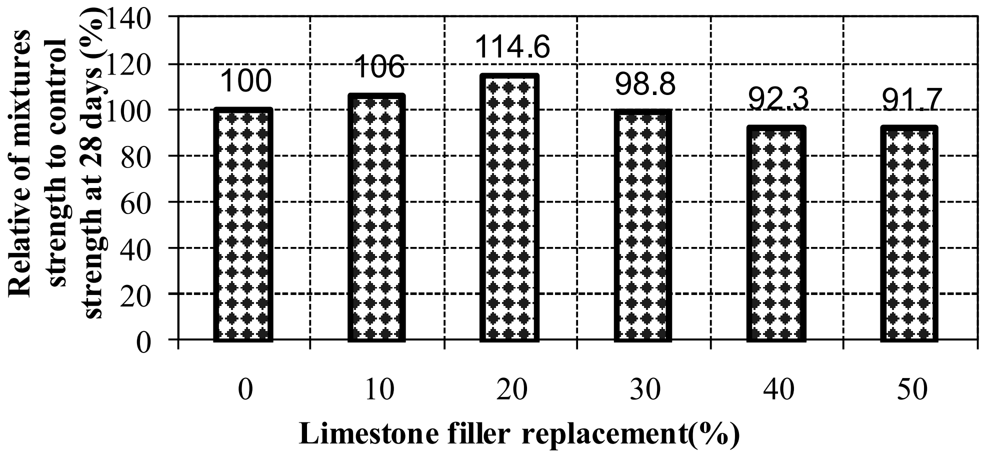

Fig.(8): Relative compressive strength of concrete mixtures to compressive strength of control concrete as a function of limestone filler percentage content

As concluded from Fig.(8) is can be seen that 20% limestone filler replacement gives the best improvement in compressive strength, The increase is found to be 14.6% at 20% replacement level compared to control concrete. Limestone cannot be considered as an inert filler, Pera [16] have studied reactions that occur during the hydration of C3S in the presence of calcium carbonate and have proved that, in cement paste, calcium carbonate has an accelerator effect on cement hydration and leads to the formation of carbosilicates and hydrated calcium carboaluminates.

Beyond 20% limestone filler replacement, compressive strength decreases with the increased filler content, Concrete with 30% of limestone filler showed a decrease in strength of about 1.2% , the decrease expanded to be 8.3 % at 50 % replacement compared to control mix. Celik observed that [6], beyond an optimal value of crushed stone dust addition, the amount of fines increases so much that the cement paste is not able to coat all fine and coarse particles (i.e. filler as well as sand). This phenomenon weakens the cement-to aggregate bond and hence leads to a loss in compressive strength for higher filler amounts than the optimal value.

Influence of the limestone filler content on the splitting tensile strength

Average values of three samples for splitting tensile strength are summarized in Table(7). Fig.(9) shows the splitting tensile strength as a function of limestone filler proportion, it can be seen that as filler content increases, splitting tensile strength also increases up to an optimal value of 20% addition, in a similar behavior to that of the compressive strength.

Table (7):Splitting tensile strength of concrete mixtures

Filler addition (%)	**0**	**10**	**20**	**30**	**40**	**50**
Splitting tensile strength (MPa)	2.5	2.8	3.2	2.5	2.4	2.3

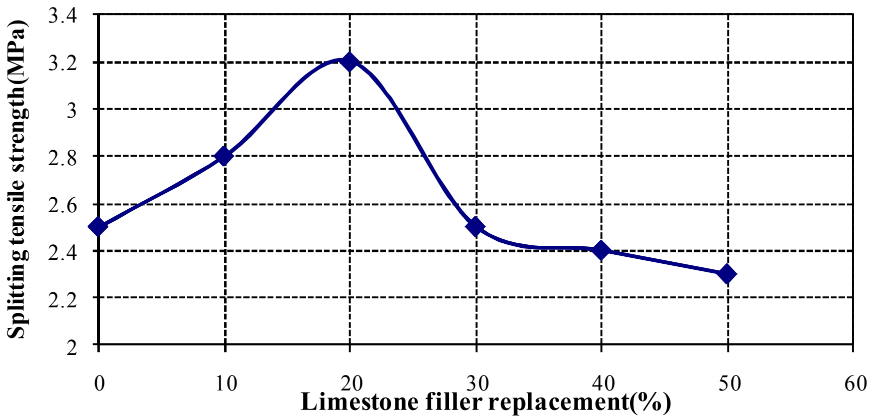

Fig. (9): The influence of percentage limestone filler replacement on the splitting tensile strength

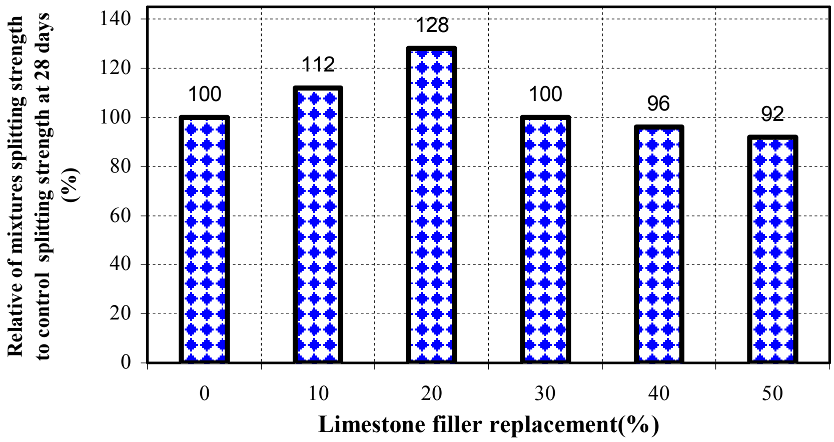

Fig.(10): Relative splitting tensile strength of concrete mixtures to splitting tensile strength of control mixture as a function of limestone filler percentage content

To compare the splitting tensile strength of concrete mixtures with added limestone filler percentages to that of the control mix, Fig.(10) is plotted. As concluded from Fig.(10) it can be seen that 20% limestone filler replacement give best improvement in splitting tensile strength, the increase is found to be 28% at 20% replacement level compared to control concrete, then splitting tensile strength decrease with the an increase of filler content beyond 20% replacement, concrete with 50% limestone filler content showing the highest decrease in splitting tensile strength of about 8% compared to control mix.

Influence of the limestone filler content on the quality of concrete

Ultrasonic pulse velocity method is considered one of the non-destructive procedures with more potential to evaluate the quality and the characteristics of concrete. It consists in measuring the transit time of an ultrasonic pulse through the material[17].

The direct ultrasonic pulse velocity values are measured at 28 days on the compressive strength samples having a 10cm direct path length using the 55 kHz longitudinal wave transducers placed in direct array. Fig.(11) shows the arrangement used for the ultrasonic pulse velocity measurement.

Fig.(11): The arrangement used for the ultrasonic pulse velocity measurement.

Measurements of three samples from each mixture were averaged to obtain the ultrasonic pulse velocity values as shown in Table(8). Fig. (12) displays ultrasonic pulse velocity results as a function of limestone filler replacement. With 10% and 20% limestone filler addition, ultrasonic pulse velocity value notably increase then decrease with limestone filler amount increase.

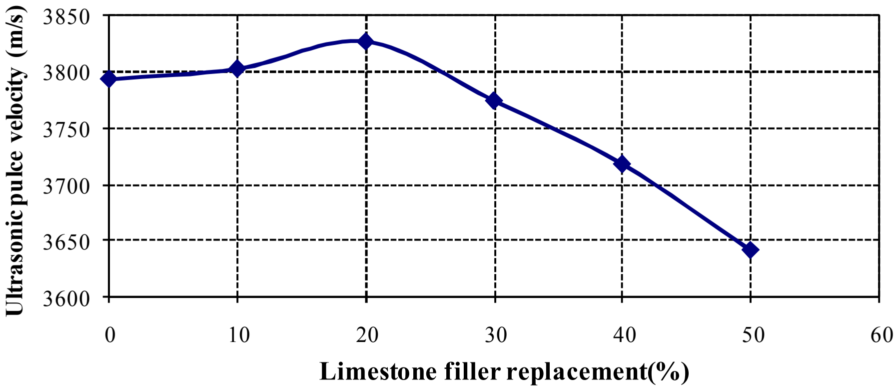

Fig. (12): The influence of percentage limestone filler replacement on the ultrasonic pulse velocity values

One of the main factors that affect the ultrasonic pulse velocity is the nature of the aggregates as the form and texture , besides, proper graduation of it which affect on the strength of the aggregate-paste interface. [18].

Table (8):Ultrasonic pulse velocity of concrete mixtures

Filler addition (%)	0	10	20	30	40	50
Ultrasonic pulse velocity(m/s)	3793	3802	3826	3774	3717	3641

According to the classification criterion for concrete based on ultrasonic pulse measurements of Table (4) [19], the concrete mixtures prepared with limestone filler content would be classified as good concrete mixtures.

Table (4):Concrete classification based on ultrasonic pulse velocity [19]

Pulse velocity (m/s)	*Concrete classification*
V > 4500	Excellent
4500 > V > 3500	Good
3500 > V > 3000	Questionable
3000 > V > 2000	Poor
V < 2000	Very Poor

Conclusions

Based on the results obtained in this study, and within the limitation of the test parameters, the following conclusions can be drawn:

1. Slump decreases with the increase of limestone filler amount, so water demand increases slightly with increasing limestone filler content.
2. The compressive strength of concrete increases with the increase in limestone filler replacement up to an optimal value, concrete made with 20% limestone filler replacement by sand showed higher compressive strength which increased by 14.6%.
3. Partial replacement of sand by limestone filler increased the splitting tensile strength, which enhanced to become 28% at 20% limestone filler replacement then decreased with the increase of limestone filler replacement.
4. With 10% and 20% limestone filler addition, ultrasonic pulse velocity values notably increased then decreased with limestone filler amount increase.

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