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Compressive and Impact Loads' Effects on The Behaviour of SIFCON Made of Plastic Waste Fibers

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ABSTRACT

SIFCON is a relatively new material and consists of slurry (cement or cement and sand), water, super plasticizers (water reducers) and fibers. In all previous research, steel fibers and other types of fibers were used, but in this study, waste plastic fibers Polyethylene Terephthalate (PET) created by cutting carbonated beverage bottles were used for the first time in the production of SIFCON.

Three volume ratios (3%, 6% and 10%) of the total volume of the concrete mixture were used to add fibers in different volume ratios, and a reference concrete mixture was created for comparison. Tests of compressive strength, impact resistance, ultrasound transmission velocity check and other tests were performed on the constructed models. Compared with the reference concrete, according to the analysis of the results. The results showed an improvement in the compressive strength it increased by (18.5%), an increase in the impact resistance by (416.67%), and a decrease in the velocity of ultrasound by (19.42%).

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1. Introduction

Concrete is one of the most widely used materials in construction due to its high resistance to compression and good resistance to external conditions such as chemical and atmospheric influences, etc., but it has a weak resistance to tensile stresses. Therefore, there is an urgent need to produce concrete with high compressive strength and high tensile resistance to be suitable for structural and semi-structural structures to concrete. To add fibers to the concrete mix in order to increase tensile strength and compressive strength.

In 1968 AD, (SIFCON) slurry infiltrated fibrous concrete was produced for the first time in the United States of America by placing the fibers to be added to the concrete inside the mold to be poured and then adding the slurry over it so that the slurry penetrates into the dense fiber network or by adding the mortar in the mold and then adding the fibers by immersing it inside the slurry.

Adding fibers to concrete is not a new idea and it has been used to produce fiber reinforced concrete (FRC), but the percentage of added fibers was very little, less than 2% of the volume of concrete to be poured because in this method, fibers are added to the concrete while it is mixed in the mixer, when the proportion of fibers increases more than 2% leads to fiber agglomeration, segregation, and non-homogeneity within the mixture and this leads to the production of weak concrete with high porosity.

The high percentage of fibers in SIFCON concrete, where the percentage of fibers in it is (3-20)%, led to the

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production of concrete with high compressive strength, high tensile strength and good ductility, much higher than FRC (I. S. Specification).

(Abdul Rahim et al., 2014) used bent steel fibers as reinforcing fibers when making SIFCON. steel fibers were used in percentages (3%, 4%, 5%), where samples of prisms with dimensions of 100 mm, 100 mm and 500 mm were used to test the flexural resistance at two loading points and the load was applied until the model failed in order to know the behaviour of steel fibers. The samples containing 5% of the fibers gave the highest flexural resistance (Abdul Rahim, Ghazaly, Ragunathan, & Shahidan, 2014).

(Pradeep & Sharmila 2015) They studied the mechanical properties of SIFCON under the influence of periodic loads and compared it with normal concrete without fibers. The slurry used in the manufacture of SIFCON consists of cement, fly ash, granular blast furnace slag and silica fume for the manufacture of SIFCON beams with dimensions of 150 mm, 100 mm and 1200 mm. It was found through this study that the hardness has increased by 134%, the compressive strength increased by 33% and the flexural strength increased by 179% compared to normal concrete. (Elnono, Salem, Farahat, & Elzanaty 2015).

(Ali & Riyadh, 2018) they studied the hybrid fibers in SIFCON (6% steel fibers with a curved end in addition to 2.5% soft steel fibers) and the results were compared with SIFCON with curved fibers. Cylindrical samples with a diameter of 100 mm and a height of 200 mm cubes with dimension of 100 mm were used . The study showed that the results obtained that SIFCON samples with hybrid fibers had higher compressive strength, higher tensile strength, higher density and higher impact resistance. Experiments were conducted after exposure to freezing and thawing cycles compared to samples with hooked fibers (Ali & Riyadh, 2018).

Researchers Mazzoli et al: They studied the shrinkage that causes cracks that occur in concrete, through the reinforced concrete industry FRC with plastic fibers to reduce cracks that occur due to shrinkage by adding different types of fibers inside the concrete (Mazzoli, Monosi, & Plescia, 2015).

The main problem with SIFCON (steel fiber) concrete is that it has a relatively high density and high thermal conductivity. In order to overcome this problem, for the first time in this research, plastic waste fibers were used polyethylene terephthalate (PET) for the manufacture of SIFCON

Usually, steel fibers are used in the production of SIFCON. In this research, for the first time, polyethylene terephthalate (PET) waste plastic fibers were used, with a length of 30 mm, a width of 1.8 mm, and a thickness of 0.29 mm and a proportion of 37.5 in the production of SIFCON.

In this study has been used three percentages of plastic fibers (3%, 6% and 10%) of the concrete volume were used, and a reference mixture of cement, sand and gravel was used only for the purpose of comparing the results to tests density, compressive strength, ultrasound velocity and impact strength tests were also performed.

2. Experimental Program

2.1 Materials

2.1.1 Cement

In this research, ordinary Portland cement-type ALMASS was used, and its physical and chemical specifications are identical to the Iraqi specifications I.Q.S. 5/2019 (Mohammed, 2022).

2.1.2 Fine Aggregate

Natural sand was used, the largest size was 1.18 mm, according to EFNARC (EFNARC, 2002) specifications and conforming to Iraqi specifications I.Q.S. No.45/1999 zone 2 (Iraq- No(45), 1999). All sand tests were carried out in the engineering laboratories of the College of Engineering at the University of Anbar as shown in table 1and 2 and fig.1.

Table 1- Physical properties of fine aggregate (Mohammed, 2022).

Type of test	Test results	Limit of Iraqi specification No.45/1984
Sulfate content So_3%	0.11%	a maximum of 0.5%
Specific gravity	2.633	
Absorption%	0.12%	
Fineness Modulus%	3.3	

Table 2- Grading of fine aggregate (Mohammed, 2022).

No	Sieve size (mm)	Cumulative passing %	Limit of Iraqi specification No.45/ 1984, (zone2)
1	10	100	100
2	4.75	97.5	100-90
3	2.36	83.83	100-75
4	1.18	70.48	90-55
5	0.6	53.6	59-35
6	0.3	15.9	30-8
7	0.15	2.5	10-0

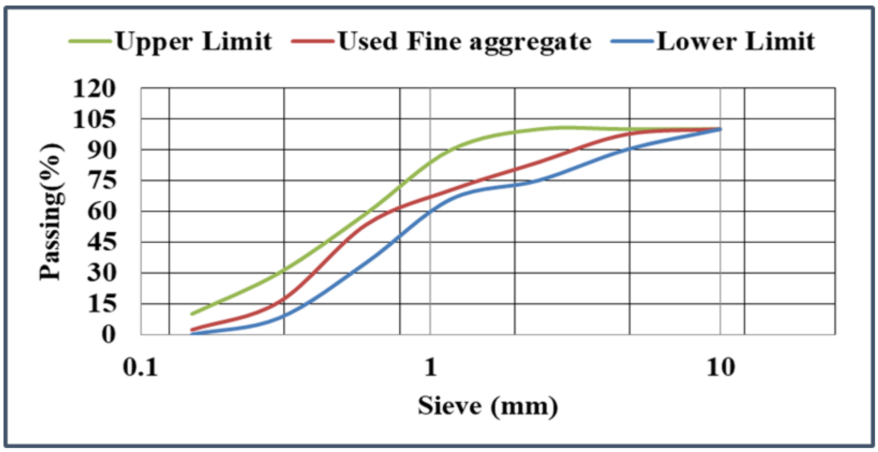

Fig. 1 Grading result of fine aggregate (Mohammed, 2022).

2.1.3 Coarse Aggregate

In this work, the crushed gravel was used with a maximum size of (10) mm. which conforms to the Iraqi specification, (ASTM C597 -09 2010) as shown in table 3 and 4 and fig. 2.

Table 3- Physical properties of coarse aggregate (Mohammed, 2022).

Type of test	Test results	Limit of Iraqi specification No.45/1984
Sulfate content	0.03%	a maximum of 0.1%
Specific gravity	2.62	
Absorption	0.81%	
% Passing 0.075mm sieve	1%	a maximum of 2%

Table 4- Sieve analysis of course aggregate (Mohammed, 2022).

No	Sieve size (mm)	Cumulative passing %	Limit of Iraqi specification No.45 /1984
1	20	100	100
2	14	100	90-100
3	10	80.7	50-85
4	5	9	0-10

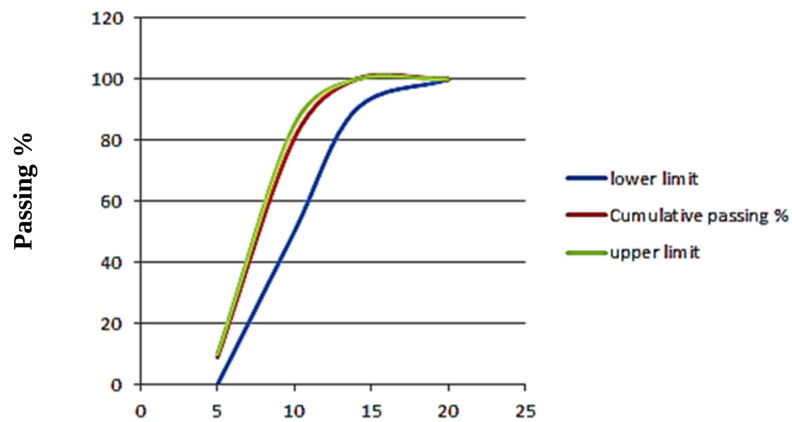

Fig. 2 Grading result of coarse aggregate (Mohammed, 2022).

2.1.4 Water

Normal water was used from the tap supplied by the main water network.

2.1.5 Fibers

In this research, waste plastic (PET) fibers were used and cut by hand, and their characteristics are shown in table 5.

Table 5- Properties of recycled PET fiber

Fiber Type	Water Absorption %	Density (kg/m^3)	Aspect ratio A_r	Width (mm)	Length (mm)	Thickness (mm)	Colour	Tensile strength (MPa)
Plastic fibers (PET)	0	1285	37.5	1.8	30	0.29	Crystalline &Green	101

2.1.6 Admixtures

water reducer additives have been used in this research super plasticizer (Viscocrete type 5930). Properties from the manufacture company are shown in table (6).

Table 6- properties of admixtures (Viscocrete type 5930).

Basis	Appearance	Density
Aqueous solution of modified Polycarboxylate	Turbid liquid	1.095 kg/lt. (ASTMC494)

2.2 Mixing Proportions

Many experiments (mini slump flow) were carried out to obtain a slurry with a suitable texture so that it penetrates into the plastic fiber network without nesting (large air spaces inside the sample) as well as without segregation in the components of the mixture, where the ratio of water to cement was changed and the percentage of superplasticizer was changed to the binder as shown in table (7).

After conducting many experiments, the ideal ratio of the slurry was reached for the manufacture of SIFCON, as shown in tables (8) and (9).

-Water to binder 30%.

-The ratio of the superplasticizer (water-reducing additive) to the weight of the binder is 1% (Viscocrete type 5930).

-The ratio of cement: sand 1:1

Table 7- Trial mixes of SIFCON slurry

Dosage of superplasticizer (Sika Viscocrete 5930) (%) by weight of cement	w/b ratio	The infiltration of slurry through the dense plastic fiber
3.7	0.33	Bad
3.7	0.3	Bad
3	0.3	Bad
2	0.3	Bad
1	0.3	Excellent

*Bad: It means that the diameter in the mini slump flow test was large, greater than (240-260) mm.
*Excellent: It means that the diameter in the mini slump flow test was within the range of (240-260) mm.

Table 8- Mixing proportion of SIFCON concrete.

Mix type	Mix proportion				
	Blended Cement (Kg/m^3)	Sand (Kg/m^3)	Plastic Fiber %	w/c ratio	SP (by wt. of binder)%
SIFCON	1005.2	1005.2	3% 6% 10%	0.3	1

Table 9- Reference mixture proportions

Material	Cement (Kg)	Sand (Kg)	Gravel (Kg)	Water (liter)
Wight (kg/m^3)	610	610	915	244

3. Preparation of Specimens

Models are prepared for SIFCON Using cubes with dimensions (100 x 100 x 100) mm and slabs with dimensions (40 x 400 x 400) mm for all research tests. The molds are cleaned, fixed well and lubricated to prevent the SIFCON samples from sticking to them when the molds are opened. The mixer must be cleaned before starting work with it. The weights of the plastic fibers were also prepared for each layer of SIFCON as the three-layer method was used. The weight of the plastic fibers for each mold is also divided into 3 groups (one group for each layer), casting on three layers.

The main components of cement, sand, water and superplasticizer are mixed in the mixer until well mixed. Where the first layer of fibers is placed in the mold where it reaches One-third of the height of the mold, then add the slurry over the fibers until the first layer of fibers is submerged subject to vibration according to percentage fiber (3% and 6% without vibrator, 10% subjected to vibrator for 20 seconds), then the second layer of fibers is added and the slurry is added on top of it until it fills two thirds of the mold. And so on the last layer. After taking out the models from the molds after 24 hours of casting, they are immersed in a basin of water for curing. The examination is carried out at the age of 7, 28 and 56 days.

4. Results and discussion

4.1 Compressive Strength.

Compression tests were performed on cubes (100 mm) the mean strength of three samples for each day was adopted, as shown in fig. 3. Through this research, it was found that the compressive strength of SIFCON with a ratio of 3% fibers was greater than that of the reference mixture by (18.5%, 6.8% and 5.6%) for ages (7,28 and 56) days respectively. And the compressive strength of SIFCON with a ratio of 6% fibers was greater than that of the reference mixture by (3.2%,0.45% and 3.4%) for ages (7,28 and 56) days respectively. Lastly Compressive strength of SIFCON with a ratio of 10% fibers was higher than the reference mixture by 0.75% at 7 days of age, as for the compressive strength at the age of (28 and 56) days, it was lower than the reference mixture by (9% and 12.8%) respectively.

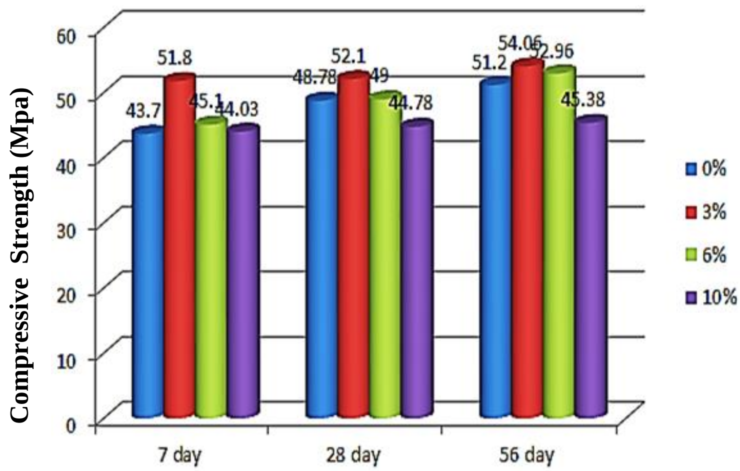

Fig. 3 Shows the relationship between compressive strength, age , and the percentage of fibers in SIFCON.

The addition of waste plastic fibers to SIFCON increased the compressive strength compared to the reference mixture, especially when adding fibers (3% and 6%), due to the good penetration of the slurry through the fiber network, which reduced the air voids and thus increased the cohesion of the fibers and cement paste, When microcracks begin to develop, the existing fibers will attempt to limit crack propagation, causing cracks to take a zigzag path and then require more energy to continue the propagation process thus increasing resistance to external stresses. (Alcan & Bingöl, 2019), as shown in fig.4 .

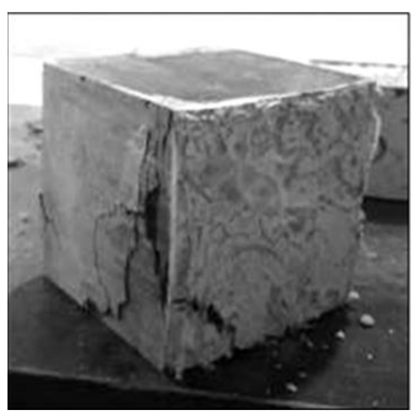

Fig. 4 Failure form of SIFCON specimen

When using a ratio of fibers (10%) in SIFCON, the compressive strength will be reduced from the reference mixture, due to the difficulty of penetration of the slurry through the plastic fiber network, and therefore the ratio of air voids are high, which leads to a weakness in the cement paste and in the cohesion strength between the cement paste and fibres, so microcracks will spread quickly and this leads to a decrease in compressive strength. (Deepesh & Jayant).

4.2 Ultrasonic pulse velocity (UPV).

This test was performed according to ASTM C597 -09 (Olutoge, Ofuyatan, Olowofoyeku, Bamigboye, & Busari 2016) an ultrasound test was done in the Engineering Consulting Bureau College Of Engineering University Of Anbar. SIFCON samples with a high percentage of plastic fibers had a lower ultrasonic velocity than the rest of the mixtures with a lower fiber content due to the presence of plastic fibers in the samples. These fibers scatter the ultrasonic wave and this leads to an increase in the time required for the wave to travel between the two ends of the sample. The ultrasound velocity in the SIFCON fiber samples (3%, 6%, 10%) was lower than the speed of the sound waves in the 0% fiber reference mixture (6.06%, 12% and 19.42%), respectively.

Increasing the proportion of fibers will increase the proportion of air voids and thus will reduce the velocity of ultrasound (Yazıcı, Aydın, Yiğiter, Yardımcı, & Alptuna, 2010).

Table 10- Ultrasonic Pulse Velocity for every percentage of plastic fibers.

The type of SIFCON according to the percentage of plastic fibers	*Ultrasonic Pulse Velocity Km/s*	*Concrete Quality*
Reference mixture Fiber 0%	4.2	Good
Fiber 3%	3.96	Good
Fiber 6%	3.75	Good
Fiber 10%	3.517	Good

4.3 Acoustic Impedance

Due to the high noise levels brought on by technological advancement, population growth, increasing use of transportation, and greater usage of electromechanical equipment for power production, heating, cooling, and other purposes, interest in acoustic impedance properties has grown in recent years. One of the most crucial factors influencing how effectively materials absorb sound is their porosity. Sound is absorbed by the enormous, continuous pores that allow acoustic energy to pass through them (Alcan & Bingöl, 2019).

The acoustic impedance represents the amount of acoustic insulation of the material and it can be calculated according to the following equation. The following table represents the acoustic impedance of all mixtures.

$$AI = \rho \times Vs \qquad (1)$$

Where: AI: Acoustic impedance.(Rayls × 10^6)

ρ: Density of concrete (kg/m^3).

Vs: Velocity of ultrasonic wave (km/sec).

Table 11- Acoustic impedance for all mixture

Mix	**Velocity (km/sec)**	**Density (kg/m^3)**	**Acoustic Impedance (ρVs) Rayls × 10^6**
Reference Mixture Fiber 0%	4.2	2337.7	9818.34
Fiber 3%	3.96	2301.7	9114.73
Fiber 6%	3.75	2269.7	8511.37
Fiber 10%	3.517	2239	7874.56

The acoustic impedance depends on the density and the speed of the sound waves, so the SIFCON mixture was 10% less acoustic conduction (Whitehurst).

4. 4. Dynamic Modulus Of Elasticity

The dynamic modulus of elasticity depends on the speed of ultrasonic waves and the density of concrete, and because the plastic fibers reduce the density of concrete, this is because its density is less than that of concrete and because the increase in the proportion of plastic fibers increases the proportion of air voids. therefore, as the percentage of plastic fibers in the mixture increases, this led to a decrease in the dynamic modulus of elasticity. The reference mixture had the highest modulus of elasticity of all the mixtures SIFCON with fiber ratio 3%, 6%, and 10%, respectively.

The dynamic modulus of elasticity depends on the density of the material and on the velocity of ultrasound waves traveling through this material and according to the following equation.

Therefore, the dynamic modulus of elasticity of the SIFCON mixture with a fiber content of 10% was the lowest dynamic modulus of elasticity due to being less dense and less velocity of ultrasound waves as shown in table12.

$$Ed = \rho \times (Vs)^2 \qquad (2)$$

Where: Ed: Dynamic modulus of elasticity.
ρ: Density of concrete.
Vs: Velocity of ultrasonic wave.

Table 12- Dynamic modulus of elasticity for all mixtures

Mix	Velocity (km/sec)	Density (kg/m^3)	Dynamic modulus of elasticity (MPa)
Reference Mixture Fiber 0%	4.2	2337.7	41237
Fiber 3%	3.96	2301.7	36094.3
Fiber 6%	3.75	2269.7	31917.65
Fiber 10%	3.517	2239	27694.8

4. 5. Impact Strength Test

Slabs with dimensions of (400 x 400 x 40) mm were used for the purpose of carrying out the impact loads test. The test was conducted at the age of 70 days by dropping a steel ball with a diameter of 7 cm and a weight of 1.4 kg freely falling on the slab from a height of 2.4 meters and the steel ball is directed to the centre of the slab by a fixed steel tube over the slab to be inspected, and the number of blows that the slab sustains before failure and full penetration of the slab by the steel ball is calculated

The table 13 shows the number of strokes and the amount of energy absorbed by all mixtures. Fig.4 shows the number of strokes that caused the first crack and the number of strokes for the final failure of each model.

Table 13- Results of the impact strength test

Mix	Number of blows to cause		Energy Absorption (Joule)		Max. Deflection (mm) at (1st) crack	Max. Deflection (mm) before ultimate failure
	First crack	Ultimate failure	First crack	Ultimate failure		
Reference Mixture Fiber 0%	3	42	98.88	1384.38	1.706	3.259
Fiber 3%	25	131	824	4317.97	0.517	3.411
Fiber 6%	18	217	59	7152.67	0.992	12.813
Fiber 10%	4	58	131.84	1911.77	0.587	13.816

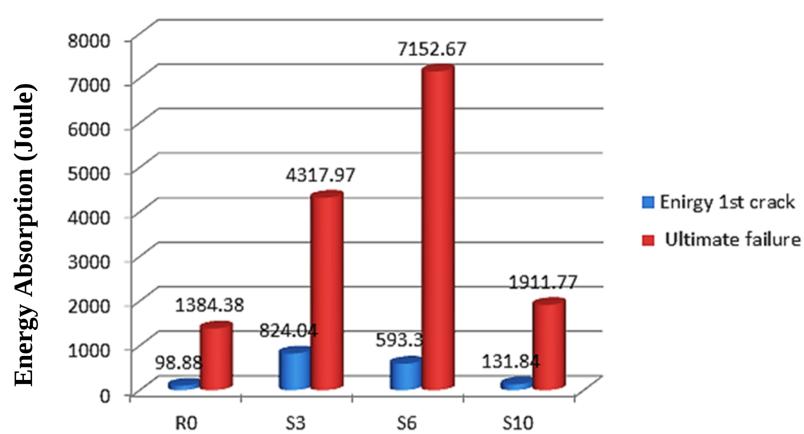

Fig. 4 Energy required to occurs first crack and ultimate failure.

When adding plastic fibers to SIFCON, the impact resistance will increase compare with reference mixture, so the SIFCON mixtures (3%, 6% and 10%) was higher than the reference mixture by (211.9%, 416.67% and 38.1%), respectively, figs. 5 and 6 show the failure pattern of the upper and lower faces of the SIFCON slabs.

The increase in impact resistance is due to the high percentage of fibers that overlap each other, which leads to the difficulty of growing or increasing microcracks, and thus the resistance increases significantly.

In the SIFCON mixture with a fiber content of 10%, the impact resistance was lower than the rest of the SIFCON mixtures, due to the very high percentage of fibers that led to the failure of the slurry penetration well, and therefore the percentage of air voids was high, which led to a decrease in its resistance. however, its resistance is still higher from the reference mixture.

Fig. 5 Upper surface of impact resistance test of samples.

Fig. 6 Lower surface patterns of failure in concrete slabs.

3.6 Relationship between impact resistance and compressive strength

In order to find the relationship between the compressive strength and the impact resistance in the SIFCON mixtures, the relationship was drawn between the compressive strength at the age of 28 days and the impact resistance at the age of 70 days, and the fig.7 was reached according to the equation 3. Fig. 7 shows that the increase in the compressive strength increases the impact strength.

$$IR = 2.895 \times fcu - 125.11 \quad (3)$$

Where: IR: Impact Resistance.
fcu: Compressive Strength
Correlation Coefficient (R^2)=0.9896

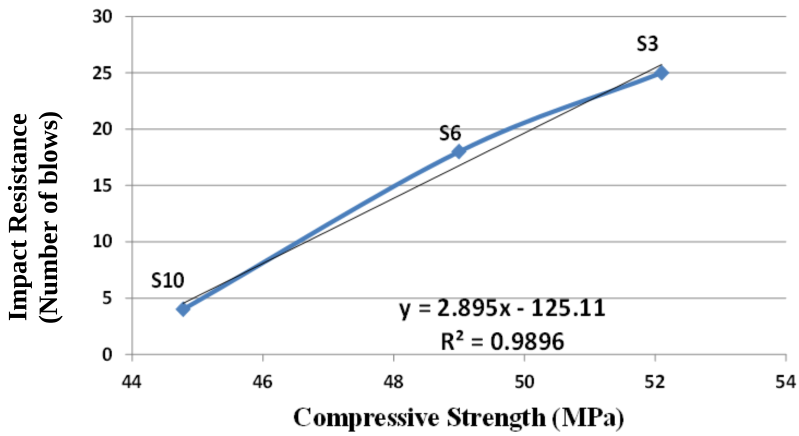

Fig. 7 Relationships between compressive strength and impact resistance at 70 day age for all concrete slabs.

5. Conclusions

The specifications of SIFCON depend on the properties of the mortar (on the properties of cement, sand and superplasticizer), the properties of the used fibers, and the method of manufacturing SIFCON. Through this research, the following conclusions were reached:

1- The strength of compression is increased by using waste plastic fibers in SIFCON, but only to a certain extent. The SIFCON with 3% fibers mixture had the best strength because a high percentage of fibers causes a reduction in strength
2- The mixture SIFCON with 10% fibers had the lowest ultrasonic wave velocity due to the high percentage of air voids and fibers in the mixture that scattered the waves within the sample. Thus the path of the waves will be longer which reduces their velocity, however, within the limits of good concrete.
3- The acoustic impedance was a function of both the material's density and the ultrasound's velocity, and the SIFCON with 10% fibers mixture had the lowest acoustic impedance since it had the lowest density and ultrasound's lowest velocity.
4- The density and the velocity of ultrasound transmission affect the dynamic modulus of elasticity, and because the SIFCON with 6% fibers mixture had a lower density and a slower ultrasonic transmission velocity than the other mixtures, it had a lower dynamic modulus of elasticity.
5- The impact strength increased with the addition of plastic fibers, and as the fraction of fibers increased, so did the impact strength. However, when the proportion of fibers is high, the rise in impact resistance is minimal, so the SIFCON with 6% fibers mixture produced the highest impact strength.
6- There is a linear direct link between compressive strength and impact resistance in the SIFCON made of plastic fibers.

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