Experimental investigation on the impact strength of hybrid fibre reinforced concrete by repeated drop weight test.

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Abstract:

The behaviour of concrete with hybrid fibre is investigated experimentally under impact loading by means of modified drop weight impact strength test (ACI committee 544.2R-89) on cubical specimen of size 100mm x 100mm x 100mm. For this work, concrete composite combining Crimped Steel Fibre of dosage 0% to 1.5% and Shortcut Glass Fibre of dosage 0.1% to 0.2% both by volume of concrete, were employed. The M25 grade of concrete is designed as per the guidelines of IS 10262.To improve the workability of the concrete, super plasticizers are added. The specimens were cured for 7 days and 28 days and tested for the impact strength by observing the number of blows required to create the first crack and also to cause failure of the specimen. According to the findings, hybrid fibre reinforced concrete has a stronger impact resistance than standard controlled concrete due to the addition of fibres. Furthermore, linear regression analysis was employed to generate the link between number of blows to cause initial crack and final failure during 7th day and 28th day. Using the Box Behnken Design (BBD) the prediction analysis was carried out for the impact strength of hybrid fibre reinforced concrete. Contour plot and surface were constructed to illustrate graphically the relation between number of blows for initial crack and final failure, volume fraction and impact strength.

Keywords: Fibres, Hybrid Fibre Reinforced Concrete, Impact Strength, Drop weight test, Box Behnken Design.

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Introduction

The concrete that is often utilised in construction is brittle and very vulnerable to impact loads, resulting in low impact and crack resistance. This is due to the fact that reinforced concrete is more durable in compression, while steel is stronger in tension. But in today's building world, a structural engineer's task is to design a structure that is not only safe, but also resists impact loads in addition to the static loads that ordinarily occur on the structure [1, 2].As a result, a well-engineered concrete should be developed with high strength and low permeability [3].Thus alternative composite materials are added to concrete to improve its properties along with durability.

Fibres in concrete have been proven to be beneficial in resisting both static and impact loads. When short, discrete, closely spaced, and uniformly dispersed fibres are added to concrete, they improve the tensile strength, flexural strength, impact resistance, and other properties of fresh concrete while also changing the structural behaviour of hardened concrete[4,5]. Hybrid Fibre Reinforced Concrete is created when two or more fibres are added to the concrete mix. The major goal of using hybrid fibres in concrete is to regulate the development of cracks at different levels, in the zone between the cement and aggregate interface, at different curing ages, and at different loading stages. The shape, aspect ratio, orientation and volume fraction of fibres influence the toughness property of concrete.

Many studies have shown that adding fibres improves the ductility of concrete by arresting micro cracks and controlling the growth of macro cracks [6]. The addition of various types of fibres considerably increases the concrete's energy absorption capability. Adding steel fibre to concrete and increasing the fibre volume percentage has been proved in numerous experiments to improve concrete's impact resistance [7].

Concrete structural parts are subjected to dynamic stress that last only a few seconds. Machine vibration, pile driving, missile attack, aeroplane crashes, earthquakes, wind gusts, and other factors can cause these loads to break. Structures that are susceptible to these forms of impact require extra care in their design.

Hybrid fibre reinforced concrete is the topic of extensive research, and the study of the behaviour of this concrete subjected to impact loading is gaining traction. Also impact is a complicated and dynamic process that encompasses crushing, shear failure, and tensile fracturing. Hence there is no regulated technique for testing concrete under impact, the available knowledge concerning its impact behaviour is insufficient. As a result, the literatures on this subject differ greatly [8, 9].

The experiment carried out to assess the impact strength is classified into two groups based on the literature review. The initial investigation is based on the examination of the specimen under impact loads applied by test equipment. The majority of these investigations are focused on steel materials. The second experiment employs apparatus with a mechanism for dropping masses from great heights. This technology is the most common application used for testing concrete and similar construction materials under impact to measure their brittleness and impact resistance.

The American Concrete Institute (ACI Committee 544.2R-89) proposes a modified drop weight type test similar to the Aggregate Impact Testing Machine to determine the impact strength of concrete with and without fibre under impact loading. The ability of a specimen to survive repeated impacts and absorb energy is used to determine the impact strength of concrete.

Research Significance

The goal of this research is to investigate the impact behaviour of concrete with varying amounts of steel and glass fibres when subjected to a modified repeated drop weight test. Many researches have looked into the impact behaviour of concrete, with some focusing on fibre reinforced concrete (which contains single fibre) and using the ACI Committee 544.2R-89 test protocol. The test results vary substantially depending on the type of load imposed and the surface over which the load is applied, according to the information accessible in the literature. Furthermore, current knowledge of the behaviour of hybrid fibre reinforced concrete under impact is insufficient, necessitating further research.As a result, the research is carried out experimentally using a modified repeated drop weight test to calculate the number of blows required to cause an initial crack and failure. The quantity of energy spent during the initial crack and collapse was also investigated on the cubical specimen.

Materials and methods

The main objective of this experimental study was to evaluate the impact strength of no fibre concrete and hybrid fibre reinforced concrete.

Materials

Cement

In this experimental work, ordinary Portland cement with specific gravity 3.1 confirming to IS.8112:1989 manufactured by M/S Ultratech was used.

Aggregates

Locally available natural sand conforming to zone II of IS383-1970 was used as fine aggregate with specific gravity 2.63, bulk density 1758kg/m^3 and water absorption 1.0%.

Crushed granites passing through IS20mm sieve and retained on IS12.5mm sieve was used as coarse aggregate conforming to IS383-1970 with specific gravity 2.69, bulk density 1782kg/m^3 and water absorption 0.1%.

Water

Potable water with pH value of 6 was used for all the concrete mixes.

Super plasticizer

Fibres in the concrete mix affect the workability and hence super plasticizing admixtures are used in concrete. Sulphonated naphthalene based super plasticizer Conplast SP430 complying with BS5075 Part 3 with specific gravity 1.20 at 20ºC was used to obtain the required workability.

Fibres

Crimped steel fibres (SF) of 0.5mm diameter and 30mm length giving an aspect ratio of 60, with density 7850 kg/m^3 and Short cut glass fibres of 0.01mm diameter and 6mm length giving an aspect ratio of 600, with density 2580 kg/m^3 were used.

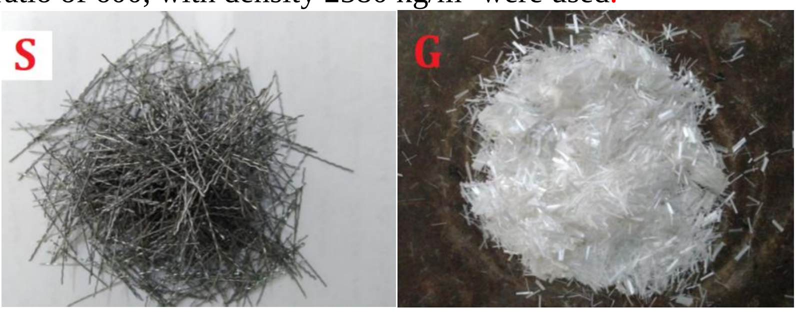


Figure 1 Crimped Steel Fibre **Figure 2** Shortcut Glass Fibre

Mix Proportion and Specimen details

M25 grade of concrete, designed as per IS10262-2009 was used for this experimental work. The mix proportion as per mix design was found to be 1:1.35:2.65 with w/c ratio 0.45.

Table 1 Mix proportion of M25 grade concrete.

Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Water kg/m^3
438	592	1175	197
1	1.35	2.65	0.45

Required quantity of cement, fine aggregates, coarse aggregates were dry mixed. Steel fibres of 0.25%, 0.50%, 0.75%, 1%, 1.25% and 1.5% by volume of concrete and Glass fibres of 0.1% to 0.25% by volume of concrete are used in this investigation. The volume fraction of these fibres varying from 0.35% to 1.70% by volume of concrete are added in the hybrid form. To this dry mix, required quantity of water and super plasticizer are added and thoroughly mixed.

For this experimental work, concrete cubes of size 100mm x 100mm x100mm were casted with and without the addition of fibres. For each mix six numbers of specimens were casted. The moulds were vibrated by keeping them on table vibrator. After 24 hours, the specimens were demoulded and transferred to curing tank and cured in water till the age of testing. Then the specimens are tested under impact loading to determine the impact strength for 7 days and 28 days.

Table 2 Various mix proportions of fibres

Sl. No	**Mix Proportion**	**Mix ID**	**Steel Fibre %**	**Glass Fibre %**
1.	Control concrete	S	0	0
2.	S 0.25 G 0.10	A	0.25	0.10
3.	S 0.25 G 0.20	B	0.25	0.20
4.	S 0.50 G 0.10	C	0.5	0.10
5.	S 0.50 G 0.20	D	0.5	0.20
6.	S 0.75 G 0.10	E	0.75	0.10
7.	S 0.75 G 0.20	F	0.75	0.20
8.	S 1.00 G 0.10	G	1.00	0.10
9.	S 1.00 G 0.20	H	1.00	0.20
10.	S 1.25 G 0.10	I	1.25	0.10

11.	S 1.25 G 0.20	J	1.25	0.20
12.	S 1.50 G 0.10	K	1.50	0.10
13.	S 1.50 G 0.20	L	1.50	0.20

Drop Weight Impact Test

To determine the impact resistance of the hybrid concrete specimens the procedure recommended by ACI committee 544.2R-89 was adopted. A hammer of weight 13.5 kg was used to apply the impact load and it is dropped continuously from a height of 413 mm over the specimen that was located at the base plate of the impact testing machine which is very similar to the Aggregate Impact Testing machine. In each test, the number of blows required to cause first crack on the cubical specimen is recorded. The same procedure is continued and then stopped when the specimen gets fractured and the number of blows required to cause this failure is noted. The impact strength was calculated using the formula,

Impact Strength, U = m g H x N

U= Impact Strength in Nm.

m = mass of the hammer in kg

g = acceleration due to gravity in m / s^2

H = height of the fall of the drop hammer in m

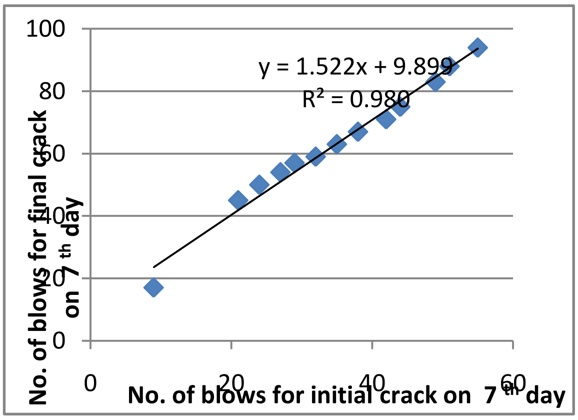
N = number of blows for first crack and ultimate crack to cause failure.

Three cubes were tested for each category and their average value is taken as the Impact Strength.

Result and discussion

Number of blows for initial and final crack

A linear regression analysis was performed between the number of blows for the initial fracture and the ultimate crack on 7^{th} day and 28^{th} day. The results revealed a strong association between them. The number of blows for the initial crack on the 7th day is 55, but it is 109 on the 28th day, which is twice as many. Similarly, the number of blows required to fail the specimen on the 7th day is 94, however the number required on the 28th day is 167, which is 1.77 times higher. On the 7th day, the difference between the number of blows for the initial crack and the final crack is 8, and on the 28th day, it is 13 for control specimen. This is owing to the fragile nature of its failure.In the case of hybrid fibre reinforced concrete specimens, however, the difference in the number of blows increased as the fibre percentage increased. Thus, with the hybrid combination of Steel fibre 1.5 percent and Glass fibre 0.2 percent, the greatest difference in number of blows was reported to be 58.



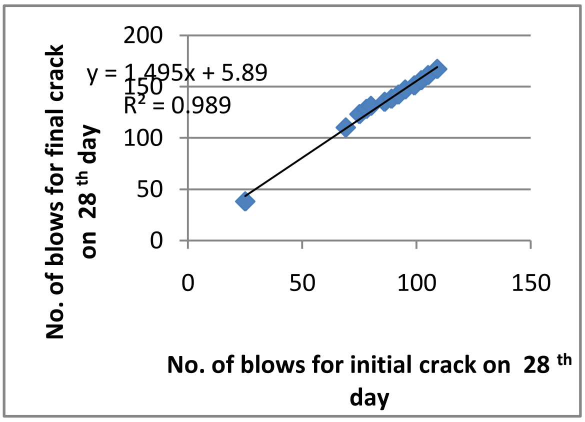


Figure 3 Relation between number of blows for initial and final crack on 7th day.

Figure 4 Relation between number of blows for initial and final crack on 28th day.

Impact Strength

The impact strength of the specimen was determined at 7 days and 28 days for first crack and for ultimate failure of the specimen. The results are tabulated as shown below.

Table 3 Impact strength of various mixes

Mix ID	Impact strength for initial crack(Nm)		Impact strength for final crack(Nm)	
	7d	28d	7d	28d
S	501.21	1392.25	946.73	2116.22
A	1169.49	3842.61	2506.05	6125.9
B	1336.56	4176.75	2784.5	6849.87
C	1503.63	4343.82	3007.26	7128.32
D	1615.01	4455.2	3174.33	7295.39
E	1782.08	4789.34	3285.71	7518.15
F	1949.15	4956.41	3508.47	7685.22
G	2116.22	5123.48	3731.23	7907.98
H	2338.98	5290.55	3953.99	8186.43
I	2450.36	5513.31	4176.75	8409.19
J	2728.81	5680.38	4622.27	8687.64
K	2840.19	5847.45	4900.72	8966.09
L	3062.95	6070.21	5234.86	9300.23

In the control specimen fracture occurs without the crack propagation but when the fibres are incorporated into the concrete it arrests the initiation and propagation of cracks. The formation of first crack on the specimen shows the effect of fibre behaviour. The sudden failure of the control concrete after the first crack shows the fracture time of the fibre reinforced concrete [6].

The impact strength of control specimen on 7th day was found to be 501.21Nm during first crack whereas for the mix L (S1.50 G0.2) it was found as 3062.95Nm which is six times greater than the control concrete. The strength of the mix L is increased by 16.36% as that of the control specimen. This is due to the fact that increase in the dosage of fibre has enhanced the impact resistance to initial crack.

When the percentage of steel fibre content in the concrete is increased the impact strength also increased, which is in accordance with the results of other researchers[11,12]. This shows that the energy absorption capacity of steel fibre is more. Also when the fibre volume increased the fracture mechanism is postponed and hence there will be delayed crack mechanism that occurs in the concrete . Thus it is found that the impact strength of concrete is increased when the steel fibre content is increased. Also addition of glass fibre improved the impact strength of concrete due to its smaller dimension and higher l/d ratio. The good bond between crimped steel fibre and the concrete attributed to the increase in impact strength [13]. The concrete containing fibres enhances the interfacial transition zone between aggregate and hybrid fibre and also increases the bonding of particles.

Impact Strength due to initial crack on 7th and 28th day.

It was found from Figure 5 & 6 that the impact strength after the appearance of the first crack on 7th day ranges from 500-3000Nm whereas on 28 th day it ranges from 1400-6000Nm.This shows that the impact energy on 28th day increased twice as that of first crack on 7th day.

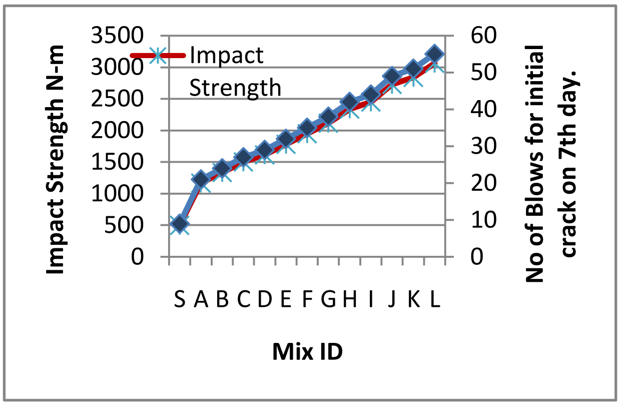


Figure 5 Impact strength due to initial crack on 7th day.

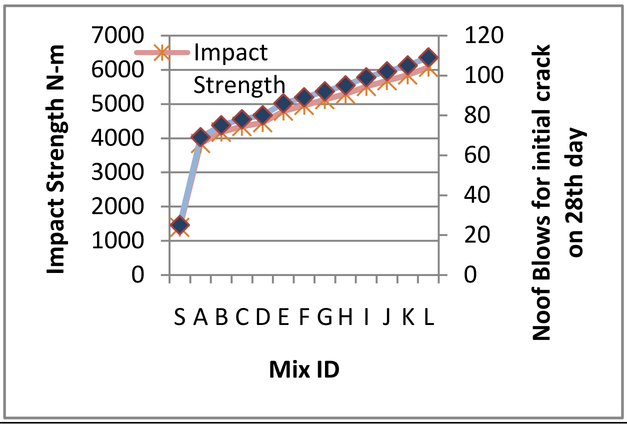


Figure 6 Impact strength due to initial crack on 28th day.

Impact Strength due to final crack on 7th and 28th day.

Similarly, the impact strength varies from 900-5200Nm for 7 days to 2100-9300Nm for 28 days, as shown in Figures 7 and 8. The impact strength improves as the curing process progresses. Because of the presence of steel fibre, the drop weight hammer generated obvious cracks in the controlled concrete, but this process is delayed in hybrid fibre reinforced concrete due to the mix of Steel and Glass fibre. The steel fibres are effective in inhibiting the growth of micro cracks.

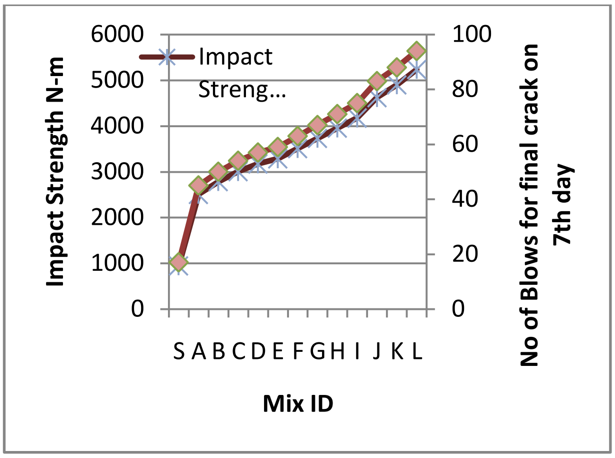


Figure 7 Impact strength due to final crack on 7th day.

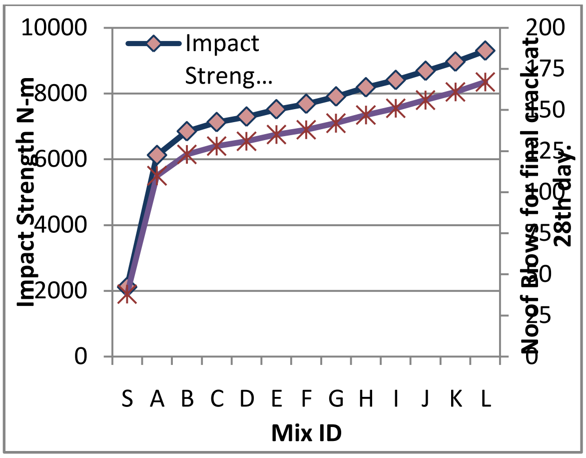


Figure 8 Impact strength due to final crack on 28th day.

Failure pattern of specimens:

The destruction of controlled concrete specimen happened instantly after the inception of cracking. The specimens lost their structural reliability and geometry due to the sudden failure and it exposed the brittle behaviour of concrete. But the hybrid fibre reinforced concrete specimens were able to resist the impact load even after the first crack formation. This reveals the ductile behaviour of HFRC and the quick destruction is controlled efficiently. The failure of the specimen is postponed due to accumulation of blooming cracks along the fragile zone surrounding the aggregate. The multiple cracks exhibited on the top surface of the HFRC specimen is due to the bridging action of the fibres. This results in forbidden brittle failure and greater energy absorbance. The compressive strength result of these specimens indicates that the concrete is durable. The structural integrity of the structure is persisting as the impact strength of the HFRC is increased.

Box-Behnken model for impact strength of concrete

Since it was first introduced, the Box-Behnken experimental design in RSM has found extensive use in engineering applications, and research on fibre-reinforced concrete has recently gained popularity.

To determine the link between the volume fractions of fibres, number of blows to cause first and final crack and the impact strength of concrete, response surface approach was used. By using a Box-Behnken design, the significance of each independent variable (volume fraction of fibres, number of blows) to the dependent variable (impact strength) and its interaction was assessed.

This design can match the quadratic model, which considers the square effect and the interaction influence of components. A box-Behnken design is used to analyse each experiment's trial at every possible combination of the variables and their values. The coefficients of the model are the linear coefficient, the independent variable interaction coefficient, and the coefficient of the quadratic term.

The estimated values of the coefficient of determination (R^2) and the adjusted coefficient of determination provide evidence regarding the adequacy of the fitted model (R^2adj). The model is deemed appropriate when the R^2 and R^2adj values are near to 1 and the P values are less than 0.05.A total of 15 runs of experiments with three variables made up the BBD in this study. With the use of analysis of variance (ANOVA), the mini tab programme evaluated the BBD data. Uncoded impact strength parameters were used to build the quadratic equation.In order to express impact strength, a second-order equation was developed utilising experimental data based on a BBD experimental design. The quadratic equation was constructed using the uncoded constants for impact strength. Consequently, the second order equation provides an expression for impact strength.

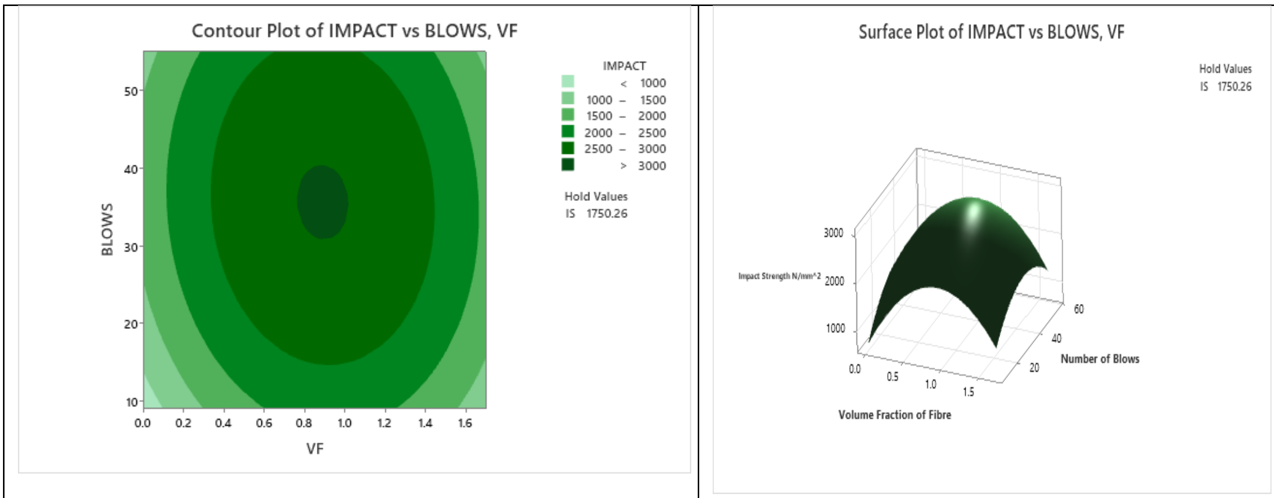


Figure 9 Contour Plot and Surface Plot for Impact strength due to Initial Crack at 7 days

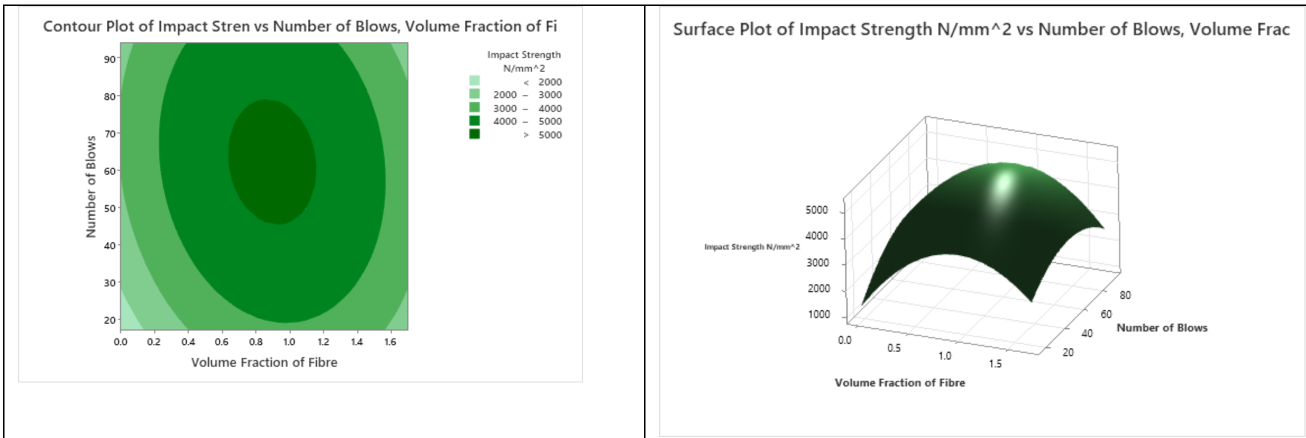


Figure 10 Contour Plot and Surface Plot for Impact strength due to Initial Crack at 28 days

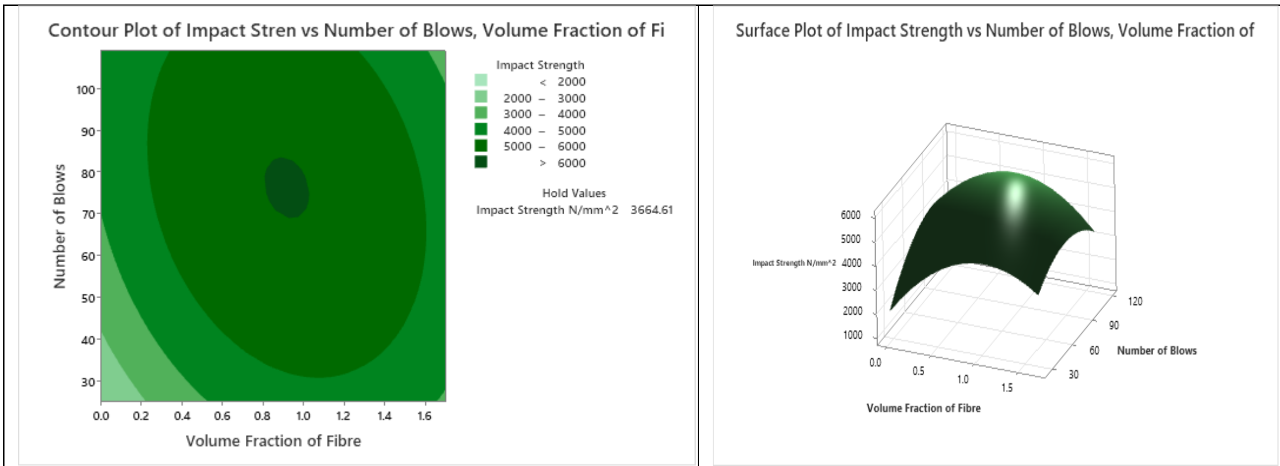


Figure 11 Contour Plot and Surface Plot for Impact strength due to Final Crack at 7 days

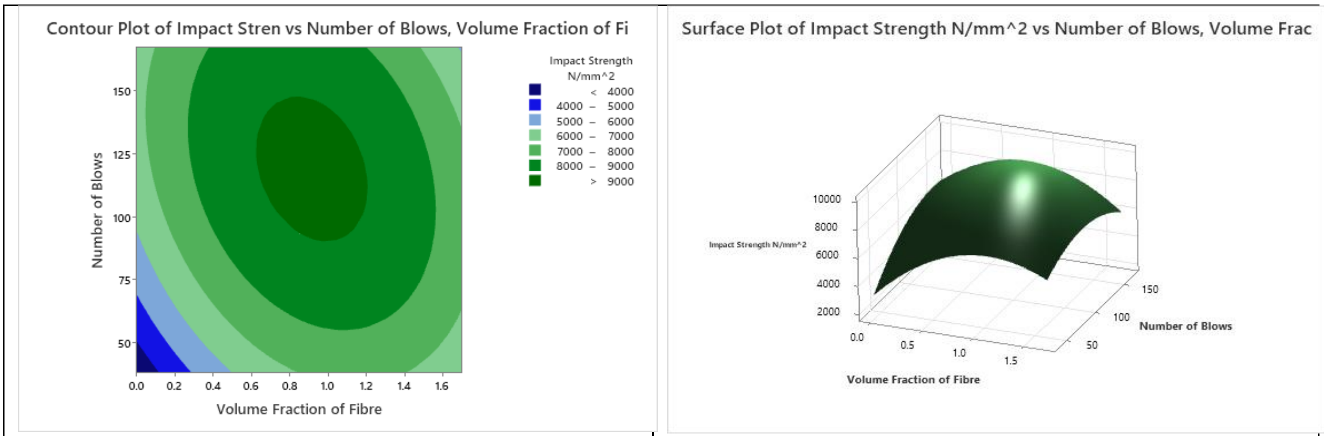


Figure 12 Contour Plot and Surface Plot for Impact strength due to Final Crack at 28 days

Conclusion

The addition of fibres has resulted in a significant increase in impact resistance. Because of its macro structure, steel fibre hindered the formation of cracks, whereas micro structured glass fibre inhibited the creation of micro cracks, and so both enhanced the impact strength of hybrid fibre reinforced concrete. These fibres, which are randomly distributed throughout the concrete mix, serve as both an energy absorber and a load transfer mechanism. The number of blows necessary to cause the first crack and also the final failure of the Hybrid fibre reinforced concrete samples are affected by the properties of fibres such as aspect ratio, tensile strength, and elastic modulus. In addition, the difference in the number of blows required for an initial crack and failure depends upon the pull out resistance of the fibre.An established technique for reinforcing soil is fibre reinforcement. These hybrid fibres are suggested for this technology.

Conflict of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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