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EFFECT OF REPLACEMENT OF CEMENT BY SILICA FUME ON THE STRENGTH PROPERTIES OF SIFCON PRODUCED FROM WASTE COILED STEEL FIBRES

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ABSTRACT

Slurry infiltrated fibre reinforced concrete (SIFCON), is a relatively new and advanced material of construction. It is fibre reinforced concrete (FRC) containing high percentage of fibres in which coarse aggregates are absent. .

SIFCON is a fabrication method in which steel fibres are preplaced in the form or in the mould to its full capacity, rather than being mixed and then cast or sprayed along with concrete. After placement of fibres, fine-grained cement based slurry is poured or pumped into the fibre network, infiltrating the air space between the fibres while conforming to the shape of the form or mould. External vibrations can also be used to aid infiltration of the slurry. SIFCON utilizes the fibres in the range of 6-20 % by volume fraction as against usual range of 1-3 % for fibre reinforced concrete. Due to such a high percentage of fibres tremendous improvement in strength properties can be expected.

In this paper effect of replacement of cement by silica fume on the properties of SIFCON is reported. SIFCON is made from waste coiled steel fibres obtained from lathe machine shop. In this study fibres having aspect ratios like 80, 90, 100, 110 and 120 are used. Specimens are cast by replacing cement by silica fume at varying percentages like 5%, 10%, 15%, 20%, 25% and 30% by weight of cement. The strength characteristics like compressive strength, tensile strength, and flexural strength and impact strength are evaluated.

***Keywords:* SIFCON, aspect ratio, waste coiled steel fibres, silica fume, compressive strength, tensile strength, flexural strength, impact strength.**

I. INTRODUCTION

High performance concrete usually contains Portland cement. However, partial cement replacement by mineral admixtures can be economically advantageous. These minerals act as filler due to their small particle size that enables their penetration between cement grains. This results in reduction in the water cement ratio to achieve a given workability[1]

Silica fume is most used mineral admixture in high strength high performance concrete. As defined by ACI 116R, it is very fine non-crystalline silica, produced in electric arc furnaces as a byproduct of the production of silicon or alloy containing silicon. It is mainly amorphous silica with high SiO2 content, extremely small particle size and large surface area. It is not precipitated silica or gel silica or colloidal silica or silica flour.[2]

In the discussion of high performance concrete role played by fibre reinforced concrete (FRC) is very important. Fibre reinforced concrete (FRC) is defined as a composite material which consists of conventional concrete reinforced by randomly dispersed short length fibres of specific geometry, made up of steel, synthetic material or natural fibres[3.] The fibres are distributed evenly throughout mix without balling or clustering[4] . The randomly oriented fibres help to bridge and arrest the cracks. As such, crack widening is gradual as compared to plain concrete[5]. This leads to better performance of concrete. Fibres have reported to be superior than wire mesh, for shortcrete. Also they overcome a difficultly in placing the mesh, especially on irregular surfaces[6].

The concept of steel fibre reinforcement is very old. Steel fibres have been used since early 1900s[7]. Presently steel fibres are considered as structural fibres as they enhance strength of the structure to a great extent[3]. The addition of steel fibres into concrete mass can dramatically increase the strength properties like compressive strength, tensile strength, and flexural strength and impact strength of concrete[8]. The strength properties of FRC can be increased by increasing the percentage of fibres in the concrete. But as the percentage of fibres increases, there are certain practical problems which have to be faced. The higher percentage i.e. higher volume content of fibres may cause balling effect in which the fibres cling together to form balls. Thus uniform distribution of fibres cannot be guaranteed, if percentage of fibres is more. Also longer fibres interfere with the aggregates during compaction thus hindering the proper orientation of fibres[9]. This fact limits the fibre content form 1 to 3 percent by volume.

The limitations of FRC and continuous ongoing demand for high performance material has led to the invention of 'Slurry infiltrated fibre reinforced concrete' (SIFCON) by Lankard in 1979. The 'Slurry infiltrated fibre reinforced concrete' is high strength, high performance material containing relatively high volume percentage of fibres as compared to FRC. SIFCON is also sometimes termed as ' High volume fibrous concrete'. In conventional FRC, the fibre content usually varies from 1 to 3 percent, while in SIFCON it varies from 6 to 20 percent by volume depending on the geometry of fibres and type of application.[8]. The material SIFCON has no coarse aggregates but has a high cementious content.

II. RESEARCH SIGNIFICANCE

SIFCON which is considered as a high performance concrete, can also be produced by using waste coiled steel fibres obtained from the lathe machine shops. Since these fibres are available locally, they can be easily used in the production of SIFCON. Due to their coiled nature they may offer more resistance to loads. The study of effect of replacement of cement by silica fume on SIFCON produced from such waste coiled fibres may result in an economic building material.

III. EXPERIMENTAL PROGRAMME

The main aim of this experimental programme is to find out effect of replacement of cement by silica fume on the strength properties of SIFCON produced from waste coiled steel fibres.

Ordinary Portland cement of 53-grade and locally available sand with a specific gravity 2.65 and fineness modulus of 2.92 was used in the experimentation. To impart additional workability, superplastisizer (1% by weight of cement) was used. The waste coiled steel fibres were procured from local lathe machine shops. The fibres were of chrome steel having density 6.8 gm/cm^3. The percentage of fibres used in the experimentation is 6%. The average thickness was 0.5 mm, with average coil diameter of 3 mm. The different aspect ratios adopted in the experimentation were 80, 90, 100, 110 and 120 giving fibre lengths 40mm, 45mm, 50mm, 55mm and 60mm respectively. The average thickness of fibres was taken into consideration in fixing the aspect ratios.

The cement mortar slurry was prepared with 1:1 proportion using w/c ratio 0.42. A superplastisizer (1% by weight of cement) was added to this slurry which increased infiltration capacity of the slurry. To study the effect of replacement of cement by silica fume on SIFCON, slurry was prepared by replacing cement by silica fume at varying percentages like 5%, 10%, 15%, 20%, 25% and 30% by weight of cement.

The moulds were filled with 6% fibres, and slurry was poured into the moulds. Vibration was given to the moulds using table vibrator. The slurry was poured until no more bubbles are seen. This ensured a thorough infiltration of slurry into the fibres. The top surface of the specimen was leveled and finished. After 24 hours the specimens were demoulded and were transferred to curing tank where they were allowed to cure for 28 days.

The effect of replacement of cement by silica fume on SIFCON was studied on compressive strength, tensile strength, flexural strength and impact strength. The cube specimens of dimension 150x150x150 mm were cast, from which the compressive strength was calculated. The specimens of dimension 150 mm diameter and 300 mm length were cast for split tensile strength. The specimens of dimension 100x100x500 mm were cast for flexural strength test. Two point loading[10] was adopted on these specimens with an effective span of 400 mm. The impact strength specimens consisted of plates of dimension 250x250x35 mm. For impact strength test four methods are described in the literature[11]. Out of these methods drop out method was used owing to its simplicity. A steel ball weighing 20 N was dropped from the height of 1 m over the specimen. The number of blows required to cause complete failure were noted. The impact energy was calculated as follows.

Impact energy = w x h x N (N-m).

Where w = weight of the ball = 20 N

h = height of fall = 1 m

N = number of blows required to cause complete failure

After 28 days of curing, the specimens were taken out of the water. Then they were tested for their respective strengths.

IV. TEST RESULTS

Tables 1, 2, 3 and 4 give the compressive strength, tensile strength, flexural strength and impact strength test results respectively, for SIFCON with and without replacement of cement by silica fume. The tables also indicate the percentage increase in the strength of SIFCON due to replacement of cement by silica fume.

The figures 1, 2, 3 and 4 give variation of compressive strength, tensile strength, flexural strength, and impact strength respectively, for SIFCON with and without replacement of cement by silica fume.

V. DISCUSSIONS ON TEST RESULTS

1) It has been observed that the compressive strength, tensile strength, flexural strength and impact strength of SIFCON goes on increasing as the aspect ratio of fibers in it goes on increasing. This is also true for SIFCON

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with and without replacement of cement by silica fume. This may be due to the fact of optimum infiltration of slurry for fibres having more aspect ratio.

Thus it can be concluded that the SIFCON produced with fibres having an aspect ratio of 120 yields the maximum strength.

2) It has been observed that percentage increase in the compressive strength of SIFCON, due to 20% replacement of cement by silica fume is 19.35%, 19.71%, 20.11%, 20.37% and 20.85% respectively for different aspect ratios of fibres like 80, 90, 100, 110, 120. It has been observed that increase in compressive strength for 20% replacement of cement by silica fume is maximum among different percentage replacements.

Thus it has been observed that as percentage replacement of cement by silica fume increases the compressive strength of SIFCON increases upto 20% and then it shows descending trend.

It has been observed that percentage increase in the tensile strength of SIFCON, due to 20% replacement of cement by silica fume is 20.84%, 20.99%, 21.26%, 21.57%, 21.82% respectively for different aspect ratios of fibres like 80, 90, 100, 110, 120. Also it has been observed that increase in tensile strength for 20% replacement of cement by silica fume is maximum among different percentage replacements.

Thus it has been observed that as percentage replacement of cement by silica fume increases the tensile strength of SIFCON increases upto 20% and then it shows descending trend.

It has been observed that percentage increase in the flexural strength of SIFCON, due to 20% replacement of cement by silica fume is 20.10%, 20.25%, 20.57%, 20.84%, 21.04% respectively for different aspect ratios of fibres like 80, 90, 100, 110, 120. Also it has been observed that increase in flexural strength for 20% replacement of cement by silica fume is maximum among different percentage replacements.

Thus it has been observed that as percentage replacement of cement by silica fume increases the flexural strength of SIFCON increases upto 20% and then it shows descending trend.

It has been observed that percentage increase in the impact strength of SIFCON, due to 20% replacement of cement by silica fume is 20.51%, 20.70%, 21.09%, 21.27%, 21.46% respectively for different aspect ratios of fibres like 80, 90, 100, 110, 120. Also it has been observed that increase in impact strength for 20% replacement of cement by silica fume is maximum among different percentage replacements.

Thus it has been observed that as percentage replacement of cement by silica fume increases the impact strength of SIFCON increases upto 20% and then it shows descending trend.

The increase in various strengths of SIFCON due to replacement of cement by silica fume may be attributed to pozzolanic activity of silica fume. Silica fume is highly reactive pozzolana. Further due to its fineness it fills the small pores of the cement paste giving very dense concrete. Due to these facts great increase in strength properties is seen. However beyond 20% replacement the strengths decrease. This may be due to less quantity of cement in the mix. Hence it may be concluded that the optimum percentage of replacement of cement by silica fume for SIFCON is 20%.

VI. CONCLUSIONS

1) The SIFCON produced with fibres having an aspect ratio of 120 yields the maximum strength.
2) Optimum percentage of replacement of cement by silica fume for SIFCON is 20%.

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Different aspect ratios of fibres	Compressive strength (MPa) of SIFCON without repl-acement. of cement by silica fume (ref. mix)	Compressive strength (MPa) of SIFCON with replacement of cement by silica fume at varying percentages and respective percentage increase in the compressive strength											
		5% replace-ment	Percentage increase in comp. strength w.r.t ref mix	10% replace-ment	Percentage increase in comp. strength w.r.t ref mix	15% replace-ment	Percentage increase in comp. strength w.r.t ref mix	20% replace-ment	Percentage increase in comp. strength w.r.t ref mix	25% replace-ment	Percentage increase in comp. strength w.r.t ref mix	30% replace-ment	Percentage increase in comp. strength w.r.t ref mix
80	30.37	31.84	4.84	32.63	7.46	34.97	15.14	36.25	19.35	35.47	16.81	34.05	12.14
90	32.44	34.08	5.07	34.88	7.54	37.60	15.92	38.83	19.71	37.93	16.94	36.49	12.50
100	33.92	35.71	5.28	36.51	7.64	39.39	16.14	40.74	20.11	39.77	17.34	38.20	12.62
110	35.55	37.55	5.62	38.32	7.79	41.46	16.64	42.79	20.37	41.85	17.72	40.08	12.74
120	37.07	39.23	5.84	40.02	7.96	43.33	16.89	44.80	20.85	43.71	17.91	41.91	13.06

Table 1—Test results of compressive strength

Table 2-- Test results of split tensile strength

Different aspect ratios of fibres	Tensile strength (MPa)of SIFCON without repl-Acement0-';[p of cement by silica fume (ref. mix))	Tensile strength (MPa) of SIFCON with replacement of cement by silica fume at varying percentages and respective percentage increase in the tensile strength											
		5% replac e-ment	Percentage increase in tensile strength w.r.t ref mix	10% replace-ment	Percentage increase in tensile strength w.r.t ref mix	15% replace-ment	Percentage increase in tensile strength w.r.t ref mix	20% replace-ment	Percentage increase in tensile strength w.r.t ref mix	25% replace-ment	Percentage increase in tensile strength w.r.t ref mix	30% replace-ment	Percentage increase in tensile strength w.r.t ref mix
80	2.92	3.09	5.86	3.16	8.13	3.38	15.91	3.51	20.84	3.44	17.85	3.30	1302
90	3.11	3.29	5.97	3.37	8.42	3.61	16.12	3.76	20.99	3.67	18.11	3.52	13.33
100	3.58	3.80	6.25	3.88	8.56	4.17	16.37	4.34	21.26	4.24	18.36	4.06	13.54
110	3.96	4.22	6.58	4.31	8.79	4.62	16.72	4.81	21.57	4.69	18.61	4.50	13.71
120	4.15	4.43	6.77	4.52	8.95	4.85	16.88	5.05	21.82	4.93	18.80	4.73	13.92

Table 3-- Test results of flexural strength

Different aspect ratios of fibres	Flexural strength (MPa) of SIFCON without repl-acement. of cement by silica fume (ref. mix)	Flexural strength (MPa) of with SIFCON replacement of cement by silica fume at varying percentages and respective percentage increase in the flexural strength											
		5% replace-ment	Percentage increase in flexural strength w.r.t ref mix	10% replace-ment	Percentage increase in flexural strength w.r.t ref mix	15% replace-ment	Percentage increase in flexural strength w.r.t ref mix	20% replace-ment	Percentage increase in flexural strength w.r.t ref mix	25% replace-ment	Percentage increase in flexural strength w.r.t ref mix	30% replace-ment	Percentage increase in flexural strength w.r.t ref mix
80	5.84	6.14	5.13	6.30	7.96	6.75	15.52	7.01	20.10	6.85	17.35	6.57	12.58
90	6.37	6.70	5.24	6.90	8.34	7.38	15.90	7.66	20.25	7.49	17.54	7.18	12.74
100	7.03	7.42	5.51	7.63	8.48	8.17	16.24	8.48	20.57	8.29	17.89	7.93	12.87
110	7.65	8.08	5.62	8.31	8.62	8.92	16.63	9.24	20.84	9.04	18.12	8.65	13.13
120	8.32	8.81	5.87	9.07	8.98	9.73	16.91	10.07	21.04	9.83	18.19	9.43	13.37

Different aspect ratios of fibres	Impact strength (N-m) of SIFCON without repl-acement. of cement by silica fume (ref. mix)	Impact strength (N-m) of SIFCON with replacement of cement by silica fume at varying percentages and respective percentage increase in the impact strength											
		5% replace-ment	Percentage increase in impact strength w.r.t ref mix	10% replace-ment	Percentage increase in impact strength w.r.t ref mix	15% replace-ment	Percentage increase in impact strength w.r.t ref mix	20% replace-ment	Percentage increase in impact strength w.r.t ref mix	25% replace-ment	Percentage increase in impact strength w.r.t ref mix	30% replace-ment	Percentage increase in impact strength w.r.t ref mix
80	4700	4960	5.24	5080	8.04	5440	15.83	5660	20.51	5540	17.83	5300	12.81
90	5020	5300	5.58	5440	8.36	5820	15.93	6060	20.70	5920	17.89	5680	13.15
100	5500	5820	5.81	5960	8.37	6400	16.36	6660	21.09	6500	18.20	6240	13.49
110	5640	5980	6.03	6120	8.51	6580	16.69	6840	21.27	6680	18.43	6420	13.82
120	5960	6340	6.37	6480	8.74	6960	16.79	7240	21.46	7080	18.83	6800	14.09

Table 4-- Test results of impact strength

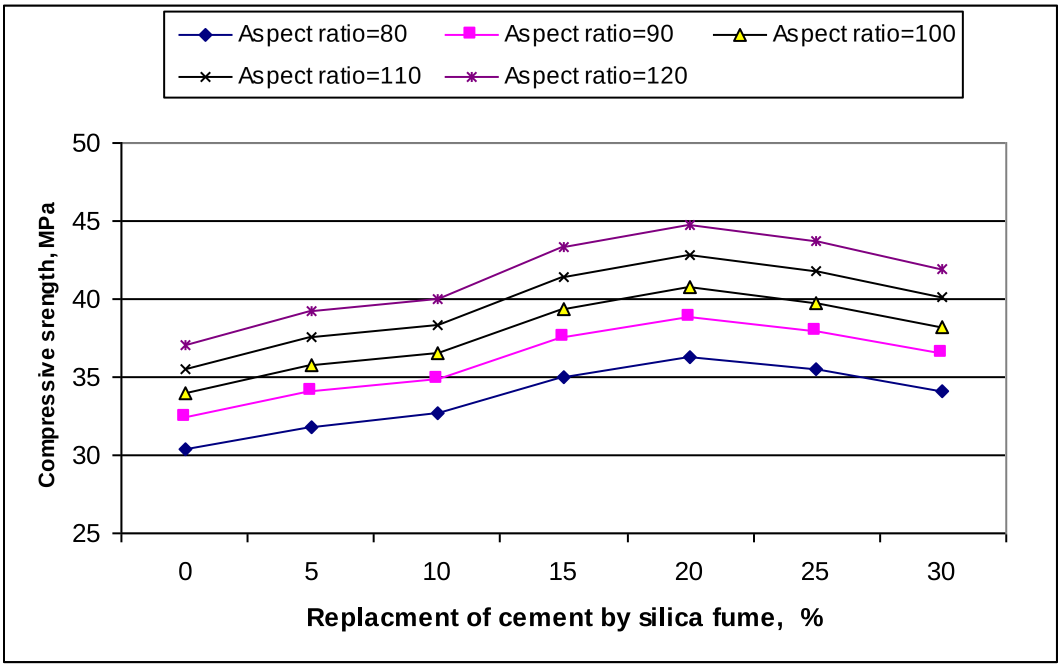

Figure 1: Variation of compressive strength of SIFCON for different percentage replacement of cement by silica fume

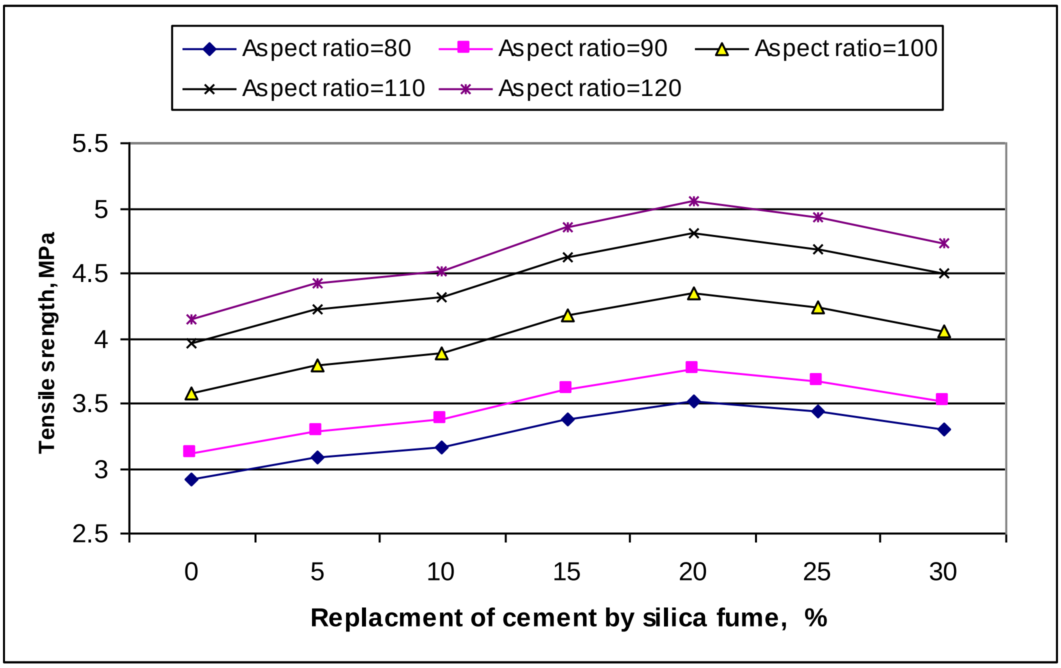

Figure 2: Variation of tensile strength of SIFCON for different percentage replacement of cement by silica fume

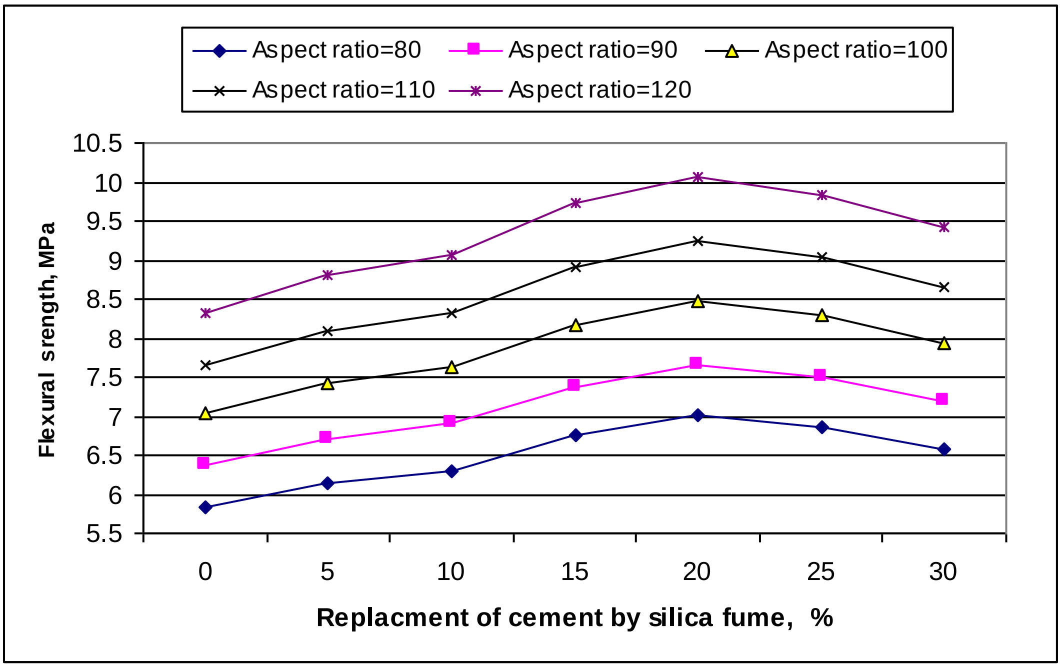

Figure 3: Variation of flexural strength of SIFCON for different percentage replacement of cement by silica fume

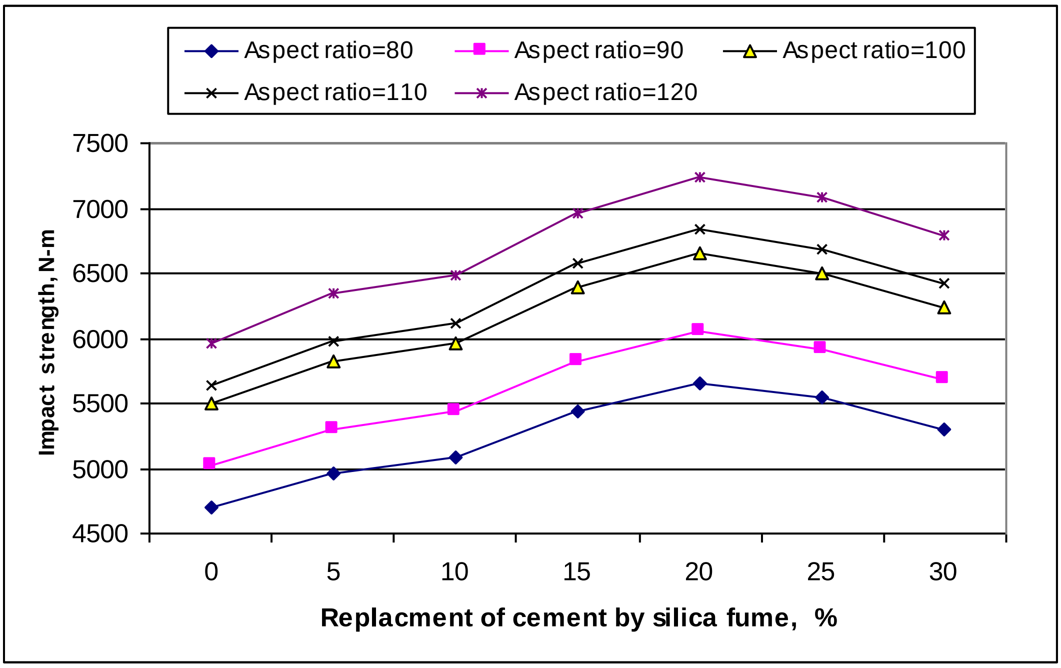

Figure 4: Variation of impact strength of SIFCON for different percentage replacement of cement by silica fume