EFFECT OF FLY ASH ON STRENGTH AND DURABILITY OF SLURRY INFILTRATED FIBROUS CONCRETE

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Several research works have been executed to examine the performance of slurry infiltrated fibrous concrete (SIFCON) under static and impact loading. But limited works have been done on the strength and durability characteristics of SIFCON made with binary blends of supplementary cementitious materials. The experimental investigation was carried out to study the strength and durability characteristics of slurry infiltrated fibrous concrete with partial substitution by fly ash (10, 15, 20, 25 & 30% as replacement of cement. SIFCON matrix containing a constant fibres content (10%) and water/binder = 0.4 were used throughout the entire investigations. The test results revealed that the incorporation of a blended cement with fly ash in SIFCON decreases the mechanical properties and improves the durability thus indicates the sorption coefficient decreases compared to control specimen. Regression model has been developed from the experimental results for estimating the compressive strength, split tensile strength, flexural strength and water permeability of SIFCON made with the binary cementitious blend of fly ash. The predicted values were satisfied with the experimental results.

Keywords: *Fly ash, SIFCON, Toughness, Ductility factor, Stiffness, Permeability, Sorption coefficient, Acid resistance*

1. Introduction

SIFCON can be considered as a high performance composite material invented by Lankard in 1983. Its possess outstanding strength and durability characteristics compared to fibres reinforced concrete and also exhibit superior performance of toughness and ductility behavior under dynamic and impact loading. The mix consists of cement slurry or flowing mortar without course aggregates. SIFCON is prepared by infiltrating the cement slurry into the bed of pre-placed fibres. It has been found in applications such as the field of construction of pavements, seismic and explosive resistant structures, bridge decks, prefabricated products and also in the military fields such as underground shelters and anti- missile hangers, rapid repair of airfield pavements, solar towers, sea –shore structures etc.

It is already focused by the authors that SIFCON subjected to static, dynamic and impact loading show better strength characteristics such as flexural strength, shearing strength and excellent ductility and toughness characteristics when compared to all other concrete composites. The strength of SIFCON depends on fibres content, fibres type, orientation of fibres, aspect ratio and slurry strength. Lankard D.R [1] studied and concluded that the improvement of concrete properties attributed by the increase of fibres content by volume. HalitYazici [2] investigated the improvement of performance of SIFCON by high volume mineral admixtures and fibre orientation and the results reveal that the flexural strength and fracture energy increases significantly due to fiber orientation and high volume mineral admixtures. HalitYazici [3] studied the mechanical properties of autoclaved SIFCON incorporating high volume of class C fly ash and concluded that the strength properties were affected positively at all replacement level of flyash and also found that the flexural and toughness characteristics were improved remarkably by increasing the fibres content. Sudarsana Rao H. [4] reported that the SIFCON slabs show better energy absorption capacity than fibre reinforced concrete, reinforced cement concrete. The energy absorption capacity was higher and lesser damage level in reinforced SIFCON containing 12% of fibres volume than unreinforced slab specimens. Sudarsana Rao H. [5] studied the influence of fibres volume in SIFCON on strength and stiffness characteristics and concluded the SIFCON with 12% fibres content exhibit higher strength and stiffness characteristics among other slab specimens. Sudarsana Rao H. [6] studied the performance of two way SIFCON

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slabs in punching shear and observed that the SIFCON containing 12% in volume of fibres shows higher shear and stiffness characteristics than all other slabs. Parameswaran V.S [7] reported the behavior of SIFCON subjected to flexure, abrasion and impact loads and the results reveal that the SIFCON specimens exhibits better ductility and higher resistance to cracking and spalling. Murat Tuyan [8] studied the pull out behavior of SIFCON and concluded that the bond strength and toughness were increased by the increase of the fibre content and fibres length and also found that the hooked end fibres shows better performance than straight fibres. Farnam Y. [9] reported the tri-axial compressive strength and poisons ratio were improved by the increase of the fibres content and confining pressure compared to high strength concrete and high performance fibres reinforced concrete. Wang M.L. [10] found that the ultimate shearing strength of specimens with parallel orientation of fibres to the direction of coring increased twice than perpendicular fibres orientation to the coring direction and also observed that strength increases by the increase of fibres content. Rafat Siddique [11] Investigated the performance of high volume class F fly ash and the results reveal that the strength characteristics decreased with increased of flyash content at 28 days and also observed that the abrasion resistance was significantly improved at the age of 91 days and 365 days of curing. Elahi A. [12] studied the mechanical and durability performance of high performance concrete with supplementary cementitius materials and conclusions are drawn that the binary blends of fyash and blast slag showed the reduction in compressive strength at all the ages and also observed that the 7.5% of silica fume improved the compressive strength compared to control mix. However the durability performances were found to improved due to addition of supplementary cementitious materials. Mostafa Jalal [13] studied the behaviour of self-compacting concrete made with the incorporation of fly ash, nano silica and silica fume and reported that the compressive strength, flexural strength and split tensile strength were decreased and also observed that the durability characteristics were improved with addition of fly ash. Caijun [14] studied the effect of flyash on mechanical properties and drying shrinkage of self compacting concrete and concluded that the workability of fresh self compacting concrete is increased and the compressive, split tensile and flexural strength decreased with increased amount of flyash in SCC. Rafat Siddique [15] concluded that the replacement of cement with fly ash decreased the compressive strength and fracture toughness and impact strength and also found that the addition increased volume of san fibres improves the impact strength.Okan Karahan [16] found that the inclusion of flyash improves the workability and decreased the compressive strength and modulus of elasticity and also observed that the freeze-thaw resistance was found to be slightly increased due to interaction between polypropylene and flyash leads to lowest drying shrinkage. Cengiz Duran Atis [17] found that the addition of steel fibers into Portland cement concrete or fly ash concrete improves the tensile strength freezing-thawing resistance and drying shrinkage and also reduces the workability and increases the sorption coefficient. However the fly ash replacement in steel fibre reinforced concrete, reduces the drying shrinkage, strength properties and improves the workability and freeze- thaw resistance. Ehsan Ghafari [18] observed that the incorporation of ternary blends of cement, fly ash and slag gives a similar performance of compressive strength compared to binary blend of cement and silica fume and also found that binary blend of cement and fly ash the mechanical properties were slightly decreased.

The aim of the research work was to investigate experimentally the strength and durability of fly ash based SIFCON specimen containing a constant fibers content of 10% with the incorporation of different percentage of fly ash as substitute of cement.

2. Experimental investigations

An experimental program was carried out for study the effect of fly ash on strength and durability characteristics of slurry infiltrated fibrous concrete containing a constant fibres content of 10% as volume fraction. The materials used, mix proportions of specimens and methods of casting, curing and testing are described as follows.

2.1 Materials used

2.1.1 Cement

Ordinary Portland cement grade 53 conforming to IS 12269 [19] was used. The specific gravity was found to be 3.1 and the initial and final setting times were found as 30 min and 340 min respectively.

2.1.2 Class F fly ash

Fly ash is the by-product of coal combustion collected by the mechanical or electrostatic precipitator. For use, fly ash should be confirmed to ASTM C618 [20] specifications for the use with the aim to enhance the strength and durability characteristics. The chemical constituents of cement and fly ash are given in Table 1. The fly ash was used in blended cements in amounts of 10, 15, 20, 26 and 30 %.

2.1.3 Fine aggregate

Sand used for the experimental program was locally procured and confirmed to grading III of Indian Standard Specifications IS: 383-1970 [21]. Locally available river sand passing through

Table 1

Physical and Chemical characteristics of Cement and Fly ash

Sl.No.	Chemical constituents	Cement (%)	Fly ash (%)
1	Silica (SiO_2)	21.8	58.3
2	Alumina (Al_2O_3)	6.6	31.7
3	Ferric oxide (Fe_2O_3)	4.1	5.9
4	Calcium oxide (CaO)	60.1	2.0
5	Magnesium oxide (MgO)	2.1	0.1
6	Sodium oxide (Na_2O)	0.4	0.8
7	Potassium oxide (K_2O)	0.4	0.8
8	Sulphuric anhydride (SO_3)	2.2	0.2
9	Loss on Ignition (LOI)	2.4	0.3
10	Specific gravity	3.1	2.31

Table 2

Matrix proportions of different mixes

Sl.No.	Type of mix	Cement kg/m^3	Flyash kg/m^3	Sand kg/m^3	Water lit./m^3	Super plasticizer lit./m^3	Fibers kg/m^3
1.	FA0	950	-	950	380	19	785
2.	FA10	855.0	95.0	950	380	19	785
3.	FA15	807.5	142.5	950	380	19	785
4.	FA20	760.0	190.0	950	380	19	785
5.	FA25	712.5	237.5	950	380	19	785
6.	FA30	665.0	285.0	950	380	19	785

BIS sieve 4.75 mm and having a specific gravity of 2.62 was used as a fine aggregate.

2.1.4 Fibers

Hooked end steel fibers having a length of 30 mm and 1.00 mm diameter with tensile strength of 1056 MPa were used. The fibers were oriented randomly.

2.1.5 Super plasticizer

To improve the workability of SIFCON, CONPLAST- 430, a high – range water reducing agent has been used as admixture for improving the flowing ability of slurry into the pre-packed fibers bed.

2.1.6 Acids

Sulphuric acid (H_2SO_4) and hydrochloric acid (HCl) solutions which were prepared with a normality of 10% were used for acid curing of the SIFCON specimens followed by 28 days of water curing .

2.2 Mix proportions

The slurry consist of a constant mix of 1:1 and water binder 0.4 were used. Fly ash is partially replaced for cement and 2% of super plasticizer is added to improve the flow ability of the slurry. The mix proportions of different mixes are presented in Table 2.

2.3 Casting and curing of specimens

Steel moulds were used for casting SIFCON specimens of required sizes. The moulds were placed on a smooth leveled surface and the inner surfaces were coated with oil for easy de-moulding of the specimens. The binder : sand ratio of 1:1 with a constant W/B ratio of 0.4 and fibre content 10% by volume fraction were used throughout the entire investigation. The slurry was thoroughly mixed and infiltrated into the pre-packed fibers bed. Hand compaction was done. After 24 hours, the specimens were demoulded and immersed in water for hardening.

2.4 Testing program

2.4.1 Compressive strength

For cube compression testing of SIFCON, 100 x 100 x 100mm size cubes were used. All the cubes were tested in a saturated condition, after wiping out the surface moisture. The cubes were tested as per BS 1881-116 [22] at the age of 3, 7 and 28 days of curing, using compression testing machine of 3000 kN capacity.

2.4.2 Split tensile strength

For the split tensile strength of concrete, cylinders of sizes 100 mm diameter x 200mm height were cast and tested at the age of 3,7 and 28 days as per the code ASTM C696-96 [23]. The split tensile strength of the cylinder was conducted on a computerized compressive testing machine of capacity 3000KN. The method covers the determination of the splitting tensile strength of cylindrical concrete specimens by applying a diametral compressive force along the length of a cylindrical specimen. The load was applied gradually until failure of the specimens.

2.4.3 Flexural strength

Three-point bending test was conducted by using a universal testing machine capable of 2000

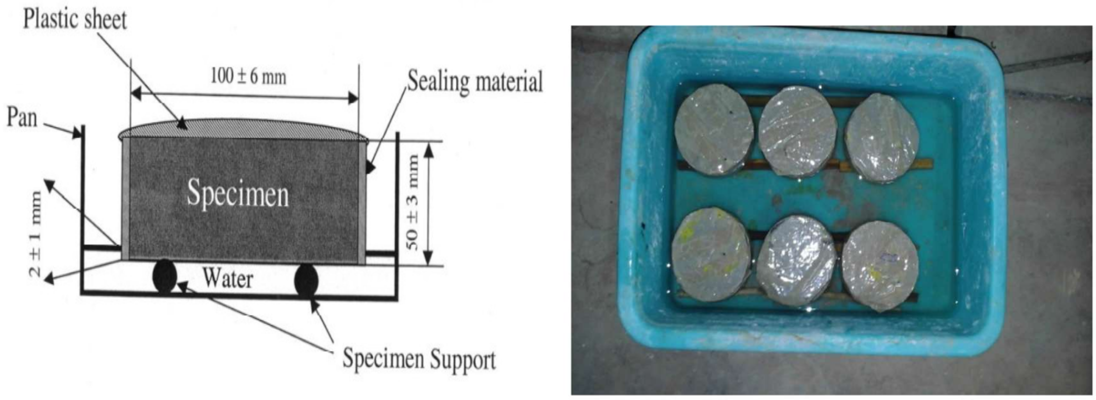
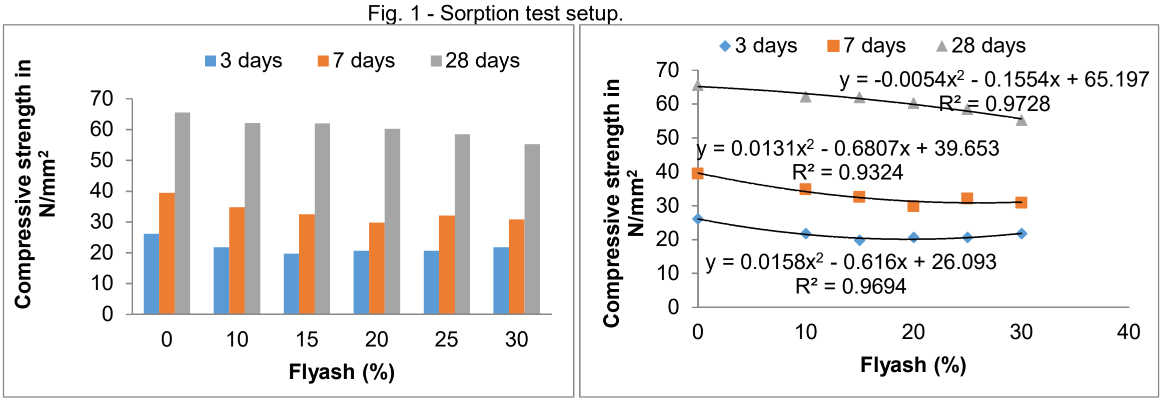


Fig. 1 - Sorption test setup.



(a) Experimental values (b) Predicted values

Fig 2- Compressive strength of different mixes.

kN. The beam specimens of size 100 x100 x500mm were cast and tested as per ASTM-C37 [24] at 28 days of curing, to determine the flexural strength and toughness characteristics of fly ash based SIFCON matrix.

2.4.4 Acid resistance test

Acid resistance test was conducted, following the procedure as per IS 1881 [22] to examine the durability characteristics of SIFCON matrix. Cubes of sizes 100 x 100 x 100 mm were cast and kept in water for curing. After 28 days the specimens were taken out and allowed to dry for one day. After that the specimens were immersed in two different solutions such as HCl and H_2SO_4. Compressive strength test was conducted by using compression testing machine of capacity 3000 kN.

2.4.5 Sorption test

To study the durability characteristics mainly focused on the sorptivity test which was carried out to determine the sorption coefficient as shown in Figure 1. The cylinder specimens having 100mm diameter and 50mm height were cast and cured in water for 28days. The procedure for the sorptivity test was followed as per ASTM C1585 [25]. The sides and top surfaces of the specimens were covered with sealant material to prevent the evaporation and the bottom surface was exposed to water. The water level in the tray was maintained at 4 to 5mm above the bottom of the specimen.

The quantity of water absorbed by the specimens at regular intervals of time 1, 5, 10, 15, 20, 30, 60, 120, 180, 240, 300 and 360 min. was observed and recorded to determine the sorption coefficient using the following relationship:

$Q/A = k\sqrt{t}$.

Where

Q is the quantity of water absorption, in mm³;

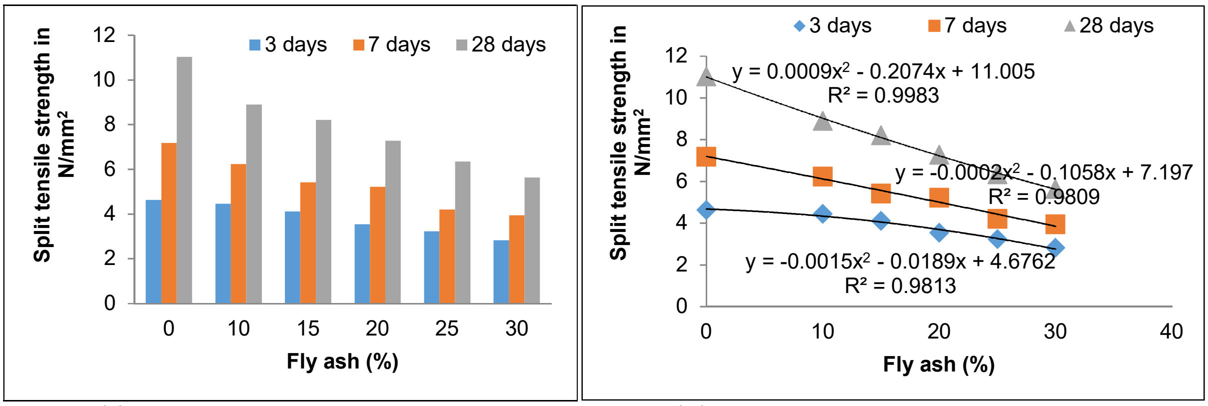
A - surface area in mm²;

t - time interval , in seconds.

3. Results and discussion

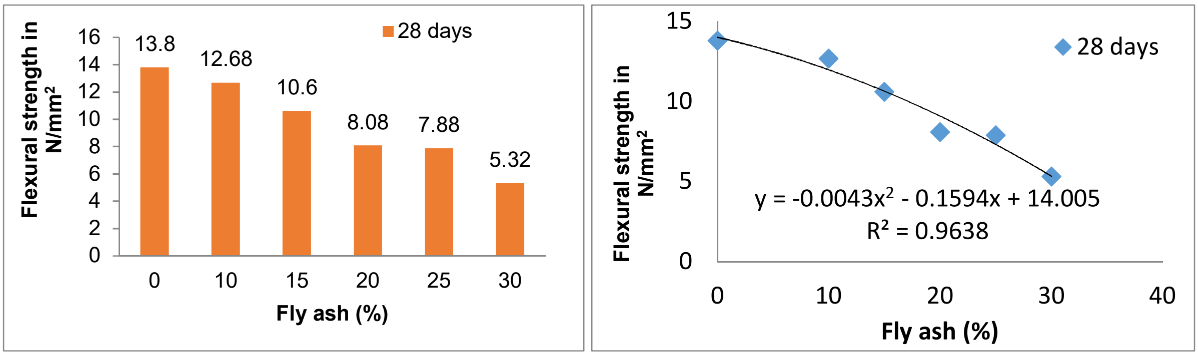
3.1 Compressive strength

The compressive strength of SIFCON specimens with different percentage of fly ash (10,15, 20, 25 &30%) containing 10% of fibres volume obtained by experiment as shown in Figure 2 (a and b) represents the predicted values which were developed from linear regression methods. From the test results observed that the compressive strengths of SIFCON made with binary blends of cement and fly ash were gradually decreased in the range of 5 % to 15.7% at 10 to 30% of fly ash replacement of cement. The strength reduction may be attributed to the dilution effect in the matrix and slow pozzolanic reaction.



(a) Experimental values (b)Predicted values

Fig 3- Split tensile strength.



(a) Experimental values (b) Predicted values

Fig 4- Flexural strength.

3.2 Split tensile strength

The indirect tensile strength of different mixes was obtained by the experimental and predicted methods. The results are shown in Figure 3 (a and b) From the test data results that the indirect tensile strength at 3, 7 and 28 days decreased with the content of fly ash added. The decrease values varies from 19% to 49 % at various replacement level of cement with fly ash from 10% to 30% in SIFCON matrix. The strength reduction is due to dilution effect of the reactive binder in the matrix and slow rate of all hydration reactions compared to control specimen.

3.3 Flexural strength

During hydration or evaporation of moisture in the capillary pores due to the incorporation of fly ash in the matrix developed a porous structure and consequently, the strength was decreased. Figure 4(a and b) shows the flexural strength of SIFCON containing various percentage of fly ash from experimental and predicted methods. From the test results reveals that the flexural strength was decreased with increase of fly ash percentage compared to control specimen.

3.4 Load Deflection response

Three-point bending test was carried out on the prisms of 100x100x500 mm based on ASTM C1609-12 to determine the flexural strength of fly ash based SIFCON subjected to static loading. Figure 5 shows the load-deflection curves of different SIFCON mixtures. The ultimate load carrying and displacement were decreased with replacement level increasing of fly ash in SIFCON. The test results show that the ultimate load and their corresponding deflection were higher in SIFCON without fly ash. Among the fly ash based SIFCON matrix, that with 10% fly ash attained higher ultimate load carrying capacity compared to all other replacement levels. Beyond 15% of fly ash, the displacement was increased without increasing the peak load.

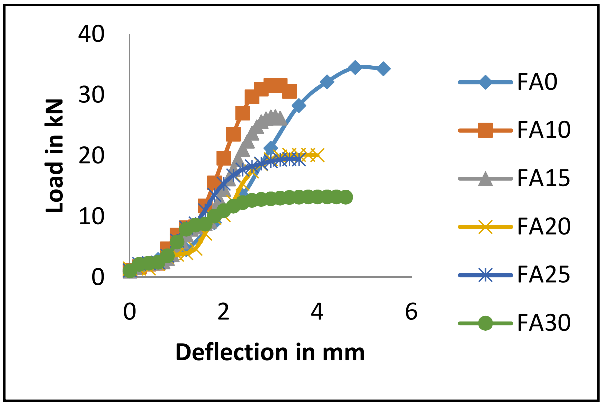


Fig. 5 - Load vs Deflection curve of different mixes.

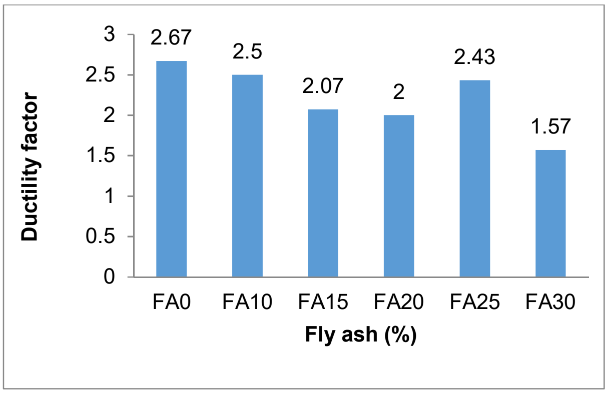


Fig.6 - Ductility factor

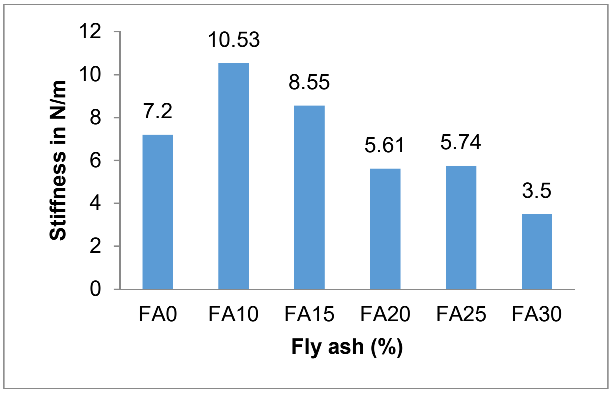
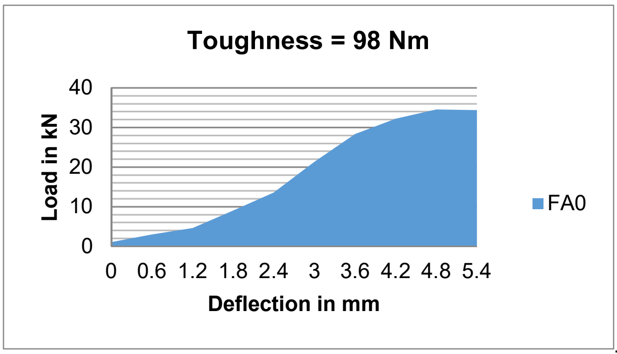
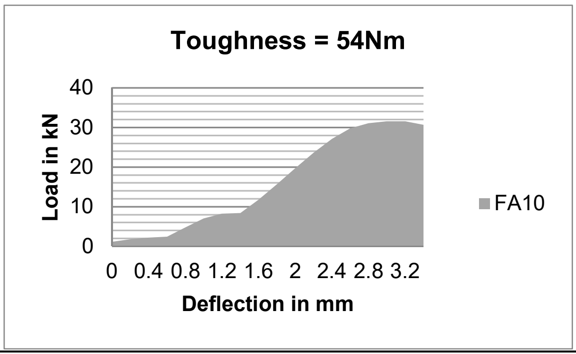


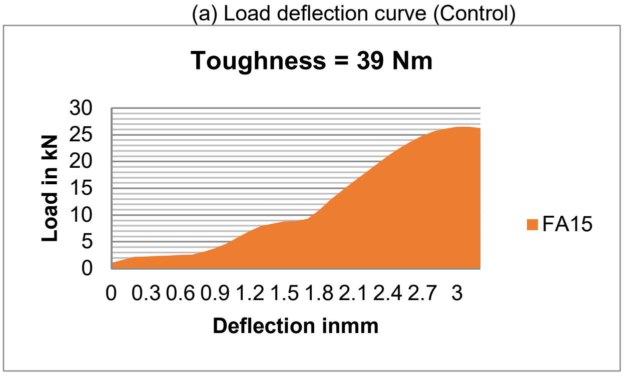
Fig. 7- Ultimate stiffness



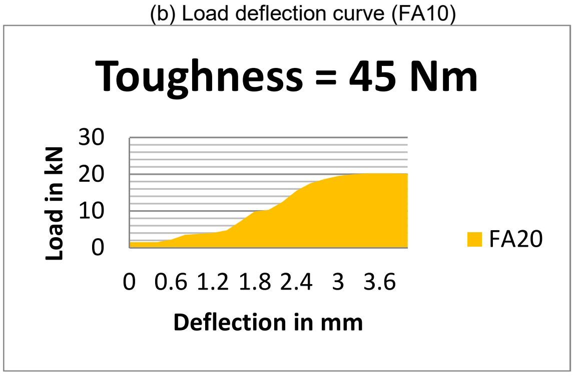
(a) Load deflection curve (Control)



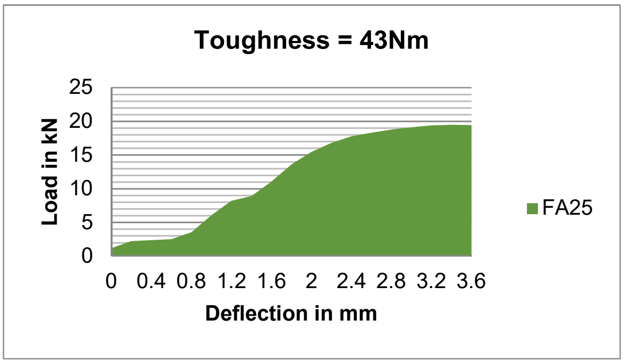
(b) Load deflection curve (FA10)



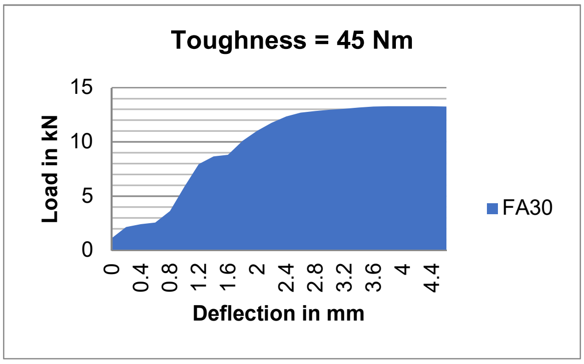
(c) Load deflection curve (FA15)



(d) Load deflection curve (FA20)



(e) Load deflection curve (FA25)



(f) Load deflection curve (FA30)

Fig. 8 Load Deflection curves .

3.5 Ductility factor

Figure 6 shows the ductility factor of samples with different replacement level of cement by the Flyash. From the test results that the ductility factor decreased with increase of the fly ash as replacement of cement. Among the fly ash based matrix the higher value of ductility factor was attained for 10% of fly ash. The incorporation of fly ash in SIFCON arresting the ductile properties due to the dilution effect and slow pozzolanic reaction. The presence of fly ash improves the bond strength between the matrix and fibres and decreases the ultimate load with a lesser amount of deflection compared to the control specimen.

Table 3

Durability characteristics of fly ash based SIFCON matrix

Sl. No.	Type of mix	% of deterioration in		Permeability of water (mm)	Sorptioncoefficient x10^{-2} mm/sec.$^{1/2}$
		H_2SO_4	HCl		
1	FA0	11.26	9.03	5.86	4.0
2	FA10	10.9	8.43	3.31	2.2
3	FA15	13.02	9.2	3.06	2.1
4	FA20	15.01	10.0	3.56	2.4
5	FA25	15.3	12.1	4.07	2.8
6	FA30	15.53	13.6	3.82	2.6

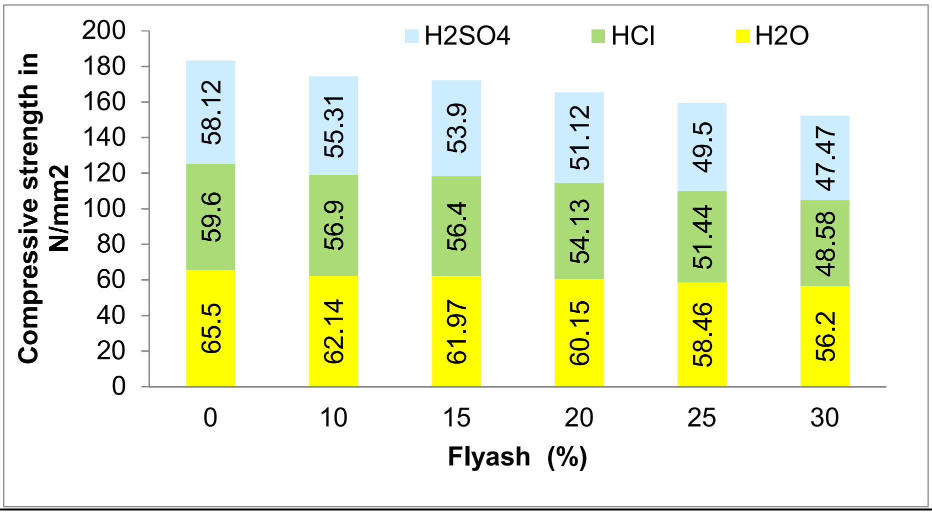


Fig. 9 - Compressive strength of different mixes in water acid curing.

3.6 Stiffness

The ultimate stiffness data of SIFCON made with various amounts of fly ash as replacement of cement are shown in Figure 7. The test results reveal that the incorporation of fly ash in SIFCON up to 15% as replacement of cement increases the stiffness characteristics compared to the control mix. The stiffness improved with 46% at 10% fly ash replaced in the matrix and also observed that the stiffness decreased with increased percentage of flyash due to dilution effect between the matrix.

3.7 Toughness

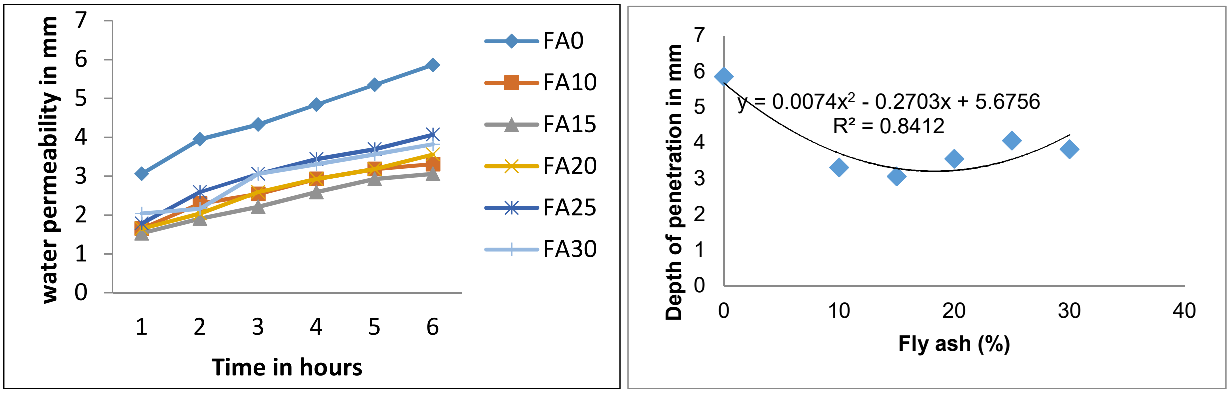
Figure 8 shows the toughness characteristics of SIFCON with different content of fly ash as replacement of cement. The toughness was evaluated by area under a load-deflection curve. The fly ash admixture improves the bond strength between the matrix and fibres. The maximum toughness was obtained for 10% fly ash as replacement of cement compared with all other replacement levels. The toughness decreased with 44.9% and 60.2% for 10% and 30% respectively compared to the control specimen.

3.8 Acid resistance test

The compressive strength of cube specimens after 28 days of acid curing such as H_2SO_4 and HCl solution after 28 days of curing in water are shown in Figure 9. It is clearly showed that the compressive strength in HCl curing shows better performance due to lesser deterioration than H_2SO_4 curing at all replacement level of flyash. When compared with control specimen, the lesser deterioration observed as 10.9% and 8.43% at 28 days of H_2SO_4 and HCl curing respectively are obtained at 10% of flyash replacement were presented in the Table 3.

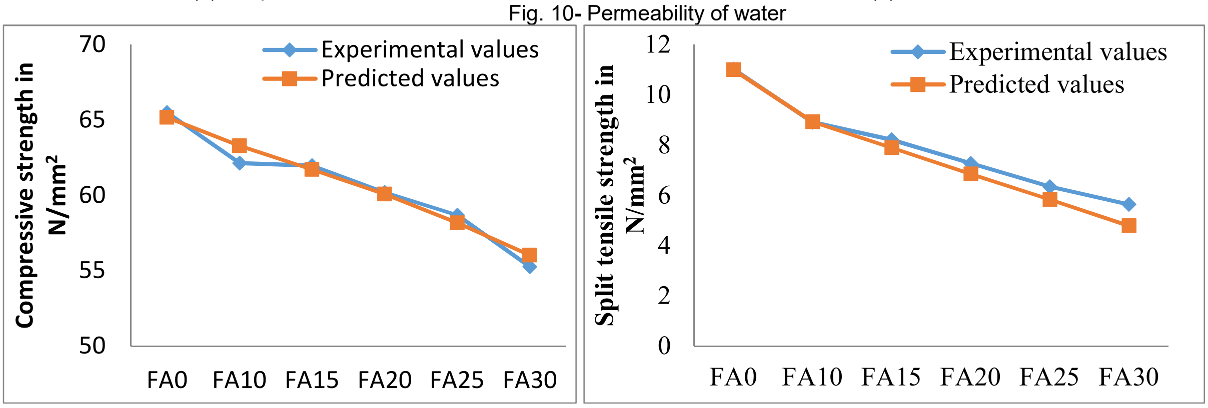
3.9 Permeability of water

The amount of water absorption due to capillary suction from the bottom was observed and measured periodically at a regular time of 1h, 2h, 3h, 4h, 5h and 6h. Figure 10(a) shows clearly the depth of water penetration increases with increasing time and also found that the lesser permeability was achieved at 15% of fly ash replaced for cement compared to all other mixes were presented in Table 3. The experimental results and predicted values are shown in Figure 9 (a and b). The incorporation of fly ash in SIFCON diminish the water permeability at all replacement level, due to filler effect and pozzolanic reaction with hydrating cement; these favour the formation of lesser porous transition zone compared to the control specimen. The test results reveal that sample with 15% fly shows better performance in terms of permeability reduction than all other replacement levels; thus indicates a good durability.

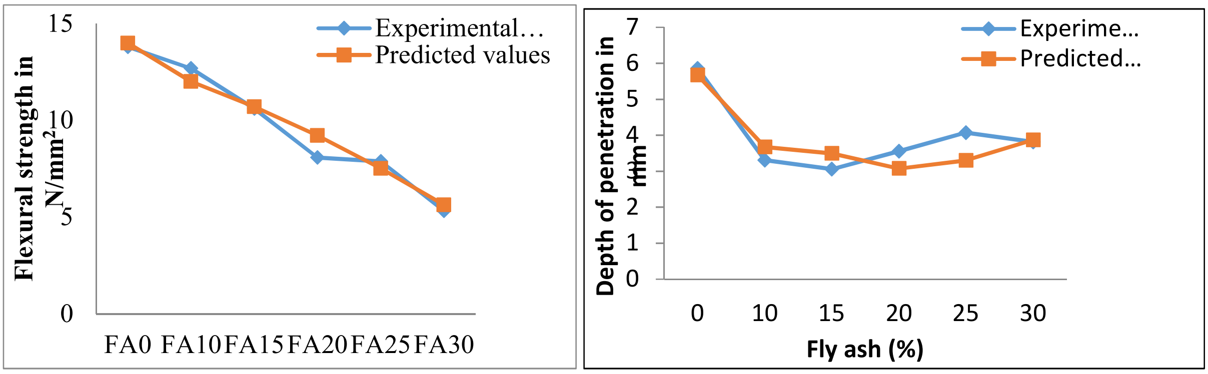


(a) Experimental values (b) Predicted values

Fig. 10- Permeability of water



(a) Compressive strength (b) split tensile strength



(c) Flexural strength (d) Permeability of water

Fig. 11 - Comparison of experimental results and predicted models.

of SIFCON. The test results show that the depth of water penetration was quite lesser at 15% of fly ash among all replacement levels. Furthermore increasing the addition of fly ash in SIFCON gets a lower rate of capillarity compared to control mixture. It may be attributed to the decrease in number of pores in the specimen due to the filler effect of an optimum amount of fly ash replacing of cement.

3.10 Sorption coefficient

The sorption coefficient of SIFCON incorporating different percentages of fly ash as partially substitute for cement is presented in Table 3. The water gain of the specimen with respect to increasing time is observed to follow an increasing trend. The sorption coefficients were decreased with increasing of fly ash replacement up to 15% indicates improving the durability characteristics. It was observed that the maximum reduction of sorption coefficient attained at 15% of fly ash leads to a value of 2.1 x 10^{-2}mm/sec.$^{1/2}$ compared to all other replacement levels. Results show that water absorption capacity of SIFCON decreases with the increase of fly ash replacement level what indicates a good durability of SIFCON. This can be attributed to the decrease of the specimen's porosity number of the specimen due to a double effect of the optimum amount of fly ash.

3.11 Regression models for strength and durability of SIFCON with BCM

A simple regression analysis has been developed using the experimental results for predicting compressive strength, split tensile strength and flexural strength of SIFCON incorporating of various percentages of fly ash (10, 15, 20, 25 & 30%). Polynomial regression technique has been adopted for developing the strength model. The polynomial regression model is in the form of :

$Y = AX^2+BX+C$ (1)

where Y is the dependent variable, X is the independent variable and A, B and C are called regression coefficient. A, B and C can be determined from polynomial regression analysis in accordance with the method of least squares. The proposed polynomial equation is used for predicting the compressive, split tensile and flexural strengths were determined from the following expressions:

$Y = - 0.005x^2 - 0.155x+65.19$ -------------(2)
- Compressive strength

$Y = 0.000x^2 - 0.207x+11$ ------------------(3)
- Split tensile strength

$Y = - 0.004x^2 - 0.159x+14$ -----------------(4)
- Flexural strength

$Y = 0.007x^2 - 0.270x+5.674$ ---------------(5)
– Permeability of water

Figure 11 shows the comparison of experimental results and predicted models on strength and durability characteristics of SIFCON made blended cements with fly ash. The predicted regression models were compared with experimental results and are shown below. Figure 11 (a, b and c) observed that the developed polynomial regression models were well satisfied with the experimental values to predict the strength characteristics. The water permeability of SIFCON made with the different replacement levels of fly ash were also predicted by using regression analysis and compared with the experimental results as shown in Figure 11(d). It was found that the regression models were well agreed to predict the durability characteristics of SIFCON made blended cement with flyash.

4. Conclusions

Based on the experimental investigations, the following conclusions were drawn:

- Partial substitution of cement with fly ash is well accepted for improving the strength and durability characteristics of SIFCON. This can be achieved in SIFCON composite due to the overall economy and protect our environment of pollution.
- The compressive strength gradually decreased from 5.1% to 15.7%, split tensile strength 19.3% to 48.9% and flexural strength 8.4% to 61.4% for 10 to 30% of fly ash replacement compared to control mix.
- The reduction in strength characteristics such as compressive, split tensile and flexural strength were lesser which is obtained at 10% of fly ash compared to all other replacement level**.** This reduction in strength may be due to slow pozzolanic reaction within the matrix.
- The incorporation of fly ash in SIFCON influences the development of bond strength due to the better interlock between the matrix and fibres that improves the ultimate stiffness. The higher ultimate stiffness was achieved at 10% of fly ash replacement compared to control specimen.
- The influence of fly ash in SIFCON consist in better performance such as reduction in deterioration and sorption coefficient thus improves the durability characteristics due to formation of less porous zone which is due to the fact that the fly ash admixture improves the matrix bond.
- Based on the experimental results, regression models were suggested to evaluate the strength and durability characteristics. The predicted values were satisfied with the experimental results.

REFERENCES

1. D.R. Lankard, Properties, applications: Slurry infiltrated Fiber Concrete (SIFCON). Concrete Concrete International,1984, **6(12)**, 44.
2. Halit yazıcı Serdar Aydın, Hüseyin Yiğiter, Y.Mert. Yardımcı and GirayAlptuna..Improvement on SIFCON performance by fiber orientation and high-volume mineral admixtures. Journal of Materials in Civil Engineering,2010, **22**(11),1093.
3. Halit Yazici, Huseyin Yigiter, SerdarAydin and Bulent Baradan. Autoclaved SIFCON with high volume Class C fly ash binder phase.Cement and Concrete Research,2006, **36**, 481.
4. H SudarsanaRao, G. Vaishali,Ghorpade.,Ramana and K. Gnaneswar, Response of SIFCON two-way slabs under impact loading. International Journal of Impact Engineering, 2010, **37**, 452.
5. H.SudarsanaRao, N.V.Ramana and K.Gnaneswar, Behaviour of restrained SIFCON two way slabs under flexure, Asian journal of Civil Engineering, 2009, **10**(4),427.
6. H.Sudarsana Rao, N.V.Ramana and K.Gnaneswar, Behaviour of simply supported steel reinforced SIFCON two way slabs in punching shear. Indian journal of Engineering and Materials Sciences 2008, **15**, 326.
7. V.S.Parameswaran,T.S Krishnamoorthy, and K. Balasubramania, Behaviour of high volume fibre cement mortar in fiber cement mortar in flexure, Cement and Concrete Composites 1990, **12**(4),293.
8. Murat Tuyan and Halit Yazıcı. Pull-out behavior of single steel fiber from SIFCON matrix. Construction and Building Materials 2012,.**35**,.571.
9. Y Farnam, M .Moosavi, M .Shekarchi and Baghezadeh,A. Behaviour of slurry infiltrated fibre concrete under triaxial compression .Cement and Concrete Research, 2010,**40**(11),1571.
10. M.L..Wang and A.K Maji. Shear Properties of slurry-infiltrated fibrous concrete. Construction and Building Materials, 1994,**8**(3),161.
11. Rafat Siddique. Performance characteristics of high-volume Class F fly ash concrete, Cement and Concrete Research , 2004, **34** , 487.
12. Elahi A., Basheer ,P.A.M., Nanukuttan S.V. , Khan Q.U.Z. Mechanical and durability properties of high performance concretes containing supplementary cementitious materials.Construction and Building Materials, 2010, **24**, 292.

13. Mostafa Jalal, Alireza Pouladkhan, Omid FasihiHarandi, Davoud Jafari. Comparative study on effects of class F fly ash, nano silica and silica fume on properties of high performanceself compacting concrete. Construction and Building Materials, 2015, **94**, 90.
14. Caijun and LJ Gengying. Mechanical properties and drying shrinkage of self compacting concrete containing fly ash. Romanian Journal of Materials, 2016, **46**(4), 480.
15. Rafat Siddique. Fracture Toughness and Impact Strength of High-Volume Class-F Fly Ash Concrete Reinforced with Natural San Fibres, Leonardo Electronic Journal of Practices and Technologies,2008,**12**, 25.
16. Okan Karahan, Cengiz Duran Atis. The durability properties of polypropylene fiber reinforced fly ash concrete. Materials and Design 2011,32, 1044-1049.
17. Cengiz Duran Atis_, Okan Karahan. Properties of steel fiber reinforced fly ash concrete.Construction and Building Materials, 2009, **23**, 392.
18. Ehsan Ghafari, seyed Ali Ghahari. Hugo Costa, Eduardo ulio, Antonio Portugal, Luisa Duraes. Effect of supplementary cementitious materials on autogenous shrinkage of ultra performance concrete, Construction and Building Materials, 2016, **127**, 43.
19. BIS 12269: 1987 Specification for 53 grade ordinary Portland cement 5th Revision, BIS, New Delhi, 1987. Reaffirmed 1999.
20. ASTM C-618, Specification for Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Portland Cement Concrete.
21. Bureau of Indian Standards, Specification for coarse and fine Aggregate from natural source for concrete IS 383-1970 (Reaffirmed 2002).
22. BS 1881-116, Testing concrete, Method for determination of compressive strength of concrete cubes, 1983.
23. ASTM C496/C496M -04, Standard test method for splitting tensile strength of cylindrical concrete specimens, Annual Book ASTM Standard.
24. ASTM-C37 (2011).Standard test method for flexural Strength of concrete (Using simple beam with third-point loading) BS-EN-12390-8 (2002). Testing hardened concrete - part 2. British Euroupean Standards.
25. ASTM International, C1585-13, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes.

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RECENZIE

Lucrarea “**Materiale pentru construcții**”, autor professor **Cristian Oliviu Burada**, a apărut la Editura Aius din Craiova. La alcătuirea ei, au fost utilizate informaţii de dată recentă, atât din punct de vedere al legislaţiei specifice în ceea ce priveşte procedurile de încercări în laboratoare pentru materialele de construcţii, evaluarea și autorizarea laboratoarelor de încercări în construcții, cât şi referitor la modalităţile de obţinere şi utilizare a unora dintre cele mai uzuale materiale.
Materialele pentru construcţii sunt analizate ca reprezentând suma produselor naturale sau artificiale care pot să fie utilizate la alcătuirea construcţiilor, atât la edificarea structurilor de rezistenţă ale acestora, cât şi la executarea diverselor finisaje .
Lucrarea este structurată în cinci capitole, astfel:

Capitolul I - Managementul și sistemul calității în construcții; modalități de introducere pe piață a materialelor, evaluarea și autorizarea laboratoarelor de încercări în construcții. Aici sunt prezentate câteva concepte actuale, legate de sistemul calităţii în construcţii, reglementările tehnice, sistemele de atestare a conformităţii produselor, precum şi informaţii utile, legate de supravegherea pieţei materialelor şi produselor pentru construcţii. Este expusă maniera europeană de implementare a sistemului calităţii în construcţii, cât și modalitățile de introducere pe piață a materialelor pentru construcții, procedurile privind evaluarea și autorizarea laboratoarelor de încercări asupra acestor materiale. Totodată, sunt definite noţiunile legate de sistemul calităţii, cât şi principiile, sistemele de atestare care stau la baza evaluării produselor, obligaţiile producătorilor de materiale de construcţii, abordate prin prisma celor mai recente norme europene și legi naționale.

Capitolul II - Proprietăți fizico-mecanice ale materialelor pentru construcții; unde sunt reliefate principalele proprietăţi ale materialelor de construcţii utilizare în mod curent, conform legislaţiei româneşti din domeniu, racordată la normele specifice europene.

Capitolul III - Tipuri de lianți utilizați la alcătuirea materilalelor pentru construcții; capitol în care sunt prezentați și analizați principalii lianți folosți la alcătuirea materialelor pentru construcții.

Capitolul IV - Materiale compozite, alcătuire, caracteristici, utilizare; unde se prezintă câteva din tendinţele actuale, moderne, privind materialele de tip compozit, alcăturea lor, precum şi utilizarea acestora ca noi componente menite să îmbunătăţească rezistenţele unor elemente structurale ale construcţiilor de orice tip. Tot în acest capitol sunt prezentate rezultate ale unor experimente de laborator efectuate pe materiale compozite, rod al activității de cercetare efectuate de autor și echipa sa de cercetători în domeniu.

Capitolul V - Determinări de laborator pe agregate; unde sunt prezentate câteva determinări specifice efectuate în laboratoare specializate, dar şi diverse modalităţi de lucru în laboratoarele de încercări, conform normelor şi procedurilor în vigoare, aparatura de ultimă oră în domeniu, descrierea operaţiunilor legate de încercările de laborator, maniera de calcul a diverselor caracteristici determinate în laborator, modalităţile de exprimare a rezultatelor determinărilor, întocmirea rapoartelor de încercări conform ultimelor prescripţii din domeniu, inclusiv înregistrarea datelor rezultate din determinările de laborator.

Studierea caracteristicilor principalelor materiale de construcţii care intră în componenţa construcţiilor este obligatorie pentru viitorii ingineri constructori, indiferent de specializarea lor.

Lucrarea apărută într-o excelentă prezentare grafică, se adresează prin conţinutul său, în egală măsură studenților de la secțiile de construcții ale universităților din România și specialiștilor care își desfășoară activitatea în domeniul construcțiilor (execuție, proiectare, cercetare).