STRENGTH PARAMETER OPTIMIZATION OF HIGH STRENGTH HYBRID FIBER REINFORCED CONCRETE USING REGRESSION ANALYSIS

P. AMSAYAZHI* , K. SARAVANA RAJA MOHAN
School of Civil Engineering, SASTRA Deemed to be University, Thanjavur, India

The strength, toughness and ductility of the High strength fiber reinforced concrete (HSFRC) is presented in this paper. the glass and polypropylene fibers are used in this study. The fiber volume fraction differs from 0.25 to 1.5. Single fibers and combined fibers in the concrete is added. From this entire study it can be understood that the hybrid fibers showed more strength, ductility and toughness when compared to the single fiber concrete. There was an increase of 67% in terms of ductility and 20% in terms of toughness in high strength hybrid fiber reinforced concrete (HSHFRC). Regression analysis is used to predict the strength, toughness and ductility of HSHFRC and HSFRC. The experimental and predicted results show a close agreement.

Keywords: *Compressive strength split tensile strength, Hybrid fiber reinforced concrete, High strength concrete, toughness, Displacement ductility.*

1. Introduction

Concrete is a brittle material and basic material for any type of construction. When the fibers are added to the concrete, it changes its property from brittle to a ductile [1]. Like this the behaviour concrete is been changed, by adding different material and to enhance the property of the concrete. As we all know concrete is good in compression and weak in tension. To enhance the tensile and flexural strength of concrete, fibers are added to it. Addition of Single fibers and multiple fibers to concrete are in practice. There are many factors, which influences the property of the fiber reinforced concrete. Like fiber distribution, aspect ratio, volume fraction, type of fiber etc. To analyze the properties of concrete in real time application, the prediction modeling increases the effectiveness and accuracy of those concrete [2]. With the help of input parameters in prediction modeling, the strength parameter of the concrete can be identified. The accuracy in a fiber reinforced concrete will be due to the fiber properties.

A mathematical equation can be developed to predict the behavior of a system to represent the real time application. The regression analysis is one type of analysis to create the mathematical equation using the statistical method. Data can be compared between experimental data and real time data and their difference can be identified. The values from compressive strength, split tensile strength and flexural strength can be taken as dependent variable. The volume fraction of the fibers used, may be single or hybrid fibers, can be taken as independent variable. Getting the prediction about dependent variable can be obtained by using the independent variables. [3]

In these study two fibers namely (polypropylene and glass) are hybridized [4] together in concrete to determine the strength properties. The engineering properties of single and hybrid fibers are identified. Many researches have proved that the hybrid fiber reinforced concrete increased the strength and toughness of the concrete. If two fibers are added to the concrete, the optimal utilization of potentiality of both fibers happens in the concrete. The compressive strength of glass fiber with volume fraction of 0.25%, 0.5%,1%,1.5% and polypropylene fiber with volume fraction of 0.25%, 0.5%,1%,1.5% and hybrid fibers of H1 (G 0.2% PP 0.8%),H2 (G 0.8% PP 0.2%), H3 (G 0.5%PP 0.5%), H4 (G 0.3% PP 0.7%), H5(G 0.7% PP 0.3%)were calculated. The main objective of this paper to determine the mechanical properties of M60 high strength hybrid fiber reinforced concrete and to their comparison with predicted vales through regression analysis[5].

2.Experimental programs

2.1 Material

The high strength hybrid fiber reinforced concrete is made with material like ordinary Portland cement of 53 grade, fine aggregate of Msand, 10mm size of coarse aggregate with specific gravity of 2.64, silica fume from ELKEM materials to act as a filler material in concrete, water reducing admixture of Tec mix 640, and fibers. The fibers used in this project are polypropylene fiber [6] of 12mm length and 13 micron m diameter, and glass fiber [7] of 12mm length and 13 micron meter diameter [8]. The properties of the fibers were taken from the manufacturer. For all the mechanical tests the fiber proportions are taken to be same with respect to its volume fraction [5].

*Autor corespondent/*Corresponding author*,
E-mail: amsayazhi@sastra.ac.in

Table 1

Details of specimens

Properties Tested	Size in mm	Number of specimens
Cube Compressive strength	150x150x150	3
Split Tensile strength	300x150ϕ	3
Modulus of Rupture [Prism]	500x100x100	3
Toughness index [prism]	500x100x100	3

Table 2

M60 grade concrete mix ratio

Cement (PPC) kg/m^3	Silica fume kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Chemical admixture kg/m^3	Water/cement ratio %
485	25	770.7	1022	5.098	0.3

Table 3

Parameters from regression analysis

S. No.	Strength Test	Regression equation for hybrid concrete	R^2 value
1	Compressive strength	$Y = (4.4909\ V_g) - (5.35\ V_p) + 79.432$	0.6012
2	Split tensile strength	$Y = (-14.762\ V_g) + (18.454\ V_p) + 4.911$	0.9925
3	Modulus of rupture	$Y = (-10.85\ V_g) + (13.581\ V_p) + 9.8662$	0.9703
4	Displacement ductility	$Y = (-0.2708\ V_g) + (1.2412\ V_p) + 4.3298$	0.9822

2.2 Specimen preparation and test description

The concrete specimens were made according to the IS standard, for each and every tests. The details the specimens are given in Table 1.

All the specimens were made with the help of moulds. The fibers will be added in batch during mixing to avoid balling effect in the concrete [9]. The water reducing admixture (super plasticizer) is added to the concrete to reduce the amount of water /cement ratio. After 24hrs, the specimens were demoulded and cured for 28 days in water. The tests for all the specimens were carried out for 7 days, 14 days and 28 days [10]. Universal testing machine was used to test all the characteristics of concrete.

2.3 Mix proportion

After many trial and errors, the mix proportions of the materials in M60 grade of concrete was obtained. The mix ratio is given in Table 2.

3. Results and discussion

3.1 Regression analysis

The equations were generatedusing the regression analysis from MSexcel. Using the independent variable, the dependent variables were calculated. This analysis is used to predict the study parameters [11]. With 96% of confidence the coefficients of regression analysis is calculate and compared. 4% error allowed. The equation of regression analysis will be like the Equ (1). For all the tests the parameters A,B,C and D vary according to the input value. The Y is the output value or the predicted value from all tests. The R^2 value is the coefficient of determination. It is taken as root of the mean squared vale of error. The accuracy of all the results were optimized by the R^2 value. The R^2 value is calculated as the following Equ (2).

$$Y = A + (B^*\ V_f) + (C^*\ V_p) + (D^*V_g) \quad (1)$$

$$R^2 = 1 - \left(\frac{\Sigma\,(residual\ value)^2}{\Sigma\ (predicted\ value)^2}\right) \quad (2)$$

The equations that are obtained by the regression analysis with their coefficients are shown in Table 3**.** With the help of these results the predicted values of various tests are obtained. The experimental values were compared with the predicted results from regression analysis as shown in Table 4, 5, 6.

3.2 Compressive strength test

Three different combinations of fibers are used in this study [13]. Therefore the regression equation for compressive strength will be analyzed for all the three different combinations of specimen separately. The equations 3, 4,5 are given with their respective R^2 value. The experimental results and predicted values are displayed in Table 4. The experimental values of 7, 14, 28 days specimen under compressive strength test shown in Fig 1

Table 4

Compressive strength test results

Fibers	Mix ratio	% of glass fiber	% of polypropylene fiber	Compressive Strength (MPa)			Predicted value for 28 days strength (MPa)
				7 Day	14 Day	28 Day	
				Average	Average	Average	
Glass (%)	0	-	-	35.5	39.5	67	66.26
	0.25	0.25	-	40.3	48.2	69.4	70.07
	0.5	0.5	-	48.2	53.6	71.3	72.25
	1	1	-	47.3	57.2	73.1	71.72
	1.5	1.5	-	42	43.5	64.2	64.68
Polypropylene (%)	0	-	-	35.5	39.5	67	69.93
	0.25	-	0.25	43.5	45.6	73.4	72.79
	0.5	-	0.5	47.1	47.8	75.8	75.03
	1	-	1	51.3	53.4	76.5	77.64
	1.5	-	1.5	53.8	52	78.2	77.79
Hybrid	H1	0.2	0.8	42	49.2	79.2	78.37
	H2	0.8	0.2	45.7	53.4	76.4	77.87
	H3	0.5	0.5	51.7	61.7	79.2	78.57
	H4	0.7	0.3	48.9	58.3	80.3	79.76
	H5	0.2	0.8	50.9	50.7	81	81.51

Table 5

Split tensile strength test results

Fibers	Mix ratio	% of glass fiber	% of polypropylene fiber	Split tensile Strength (MPa)			Predicted value for 28 days strength (MPa)
				7 Day	14 Day	28 Day	
				Average	Average	Average	
Glass (%)	0	-	-	0.9	3.1	4.3	4.40
	0.25	0.25	-	2.5	4.7	5.9	5.78
	0.5	0.5	-	3.4	5.6	6.8	6.73
	1	1	-	3.8	6	7.2	7.35
	1.5	1.5	-	2.9	5.1	6.3	6.25
Polypropylene (%)	0	-	-	0.9	3.1	4.3	4.40
	0.25	-	0.25	3.5	5.7	6.9	6.85
	0.5	-	0.5	4.8	10.4	11.6	8.29
	1	-	1	7.1	9.3	10.5	10.44
	1.5	-	1.5	3.9	5.6	8.3	11.62
Hybrid	H1	0.2	0.8	4.2	6.4	7.6	8.01
	H2	0.8	0.2	8.4	10.6	11.8	10.23
	H3	0.5	0.5	4	8.1	9.3	10.45
	H4	0.7	0.3	5.9	9.2	11.9	9.12
	H5	0.2	0.8	4.4	6.6	7.8	10.60

Table 6

Modulus of rupture test results

Fibers	Mix ratio	% of glass fiber	% of polypropylene fiber	Flexural Strength (MPa)			Predicted value for 28 days strength (MPa)
				7 Day	14 Day	28 Day	
				Average	Average	Average	
Glass (%)	0	-	-	2.1	5.2	7.3	7.1
	0.25	0.25	-	4.2	6.2	9.6	9.8
	0.5	0.5	-	0.5	7.2	11.4	11.6
	1	1	-	5.4	6.3	12.9	12.6
	1.5	1.5	-	3.9	6.1	10.2	10.3
Polypropylene (%)	0	-	-	2.1	5.2	7.3	7.1
	0.25	-	0.25	2.9	8.1	9.63	9.33
	0.5	-	0.5	3.4	8.3	11.3	11.85
	1	-	1	3.5	9.6	13.8	13.43
	1.5	-	1.5	4.2	7.3	10.3	10.40
Hybrid	H1	0.2	0.8	4.3	8	12.4	12.14
	H2	0.8	0.2	3.5	8.1	12.3	13.78
	H3	0.5	0.5	5.2	9.5	14.1	13.94
	H4	0.7	0.3	4.2	7.2	14.9	12.96
	H5	0.2	0.8	3.9	7	13.2	14.05

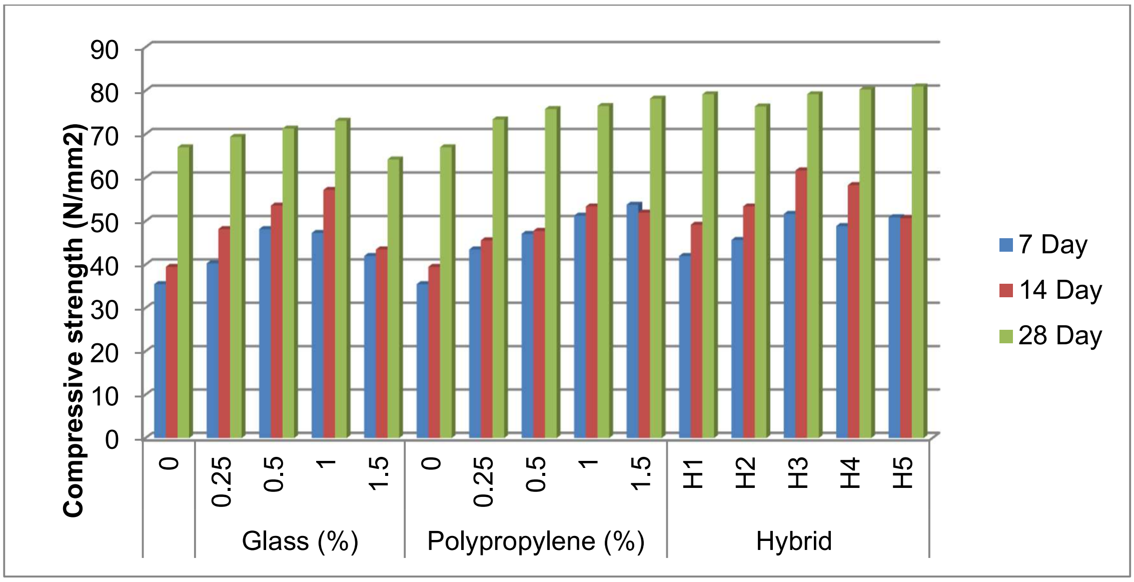

Fig 1 - Compressive strength test results.

For glass fiber,

$y = (-13.032\ V_f^2) + (18.497\ V_f) + 66.262$ (3)

$R^2 = 0.8732$

For polypropylene,

$y = (-4.9518\ V_f^2) + (12.665\ V_f) + 69.936$ (4)

$R^2 = 0.9693$

For hybrid,

$y = (4.4909\ V_g) - (5.35\ V_p) + 79.432$ (5)

$R^2 = 0.6012$

3.3 Split tensile strength test

The high strength fiber reinforced concrete cylinder specimens were casted and tested for split tensile strength [12,13]. The regression analysis has been done for all three categories of specimen and each category of fibrous specimen gave the Equ 6, 7, 8. The experimental results and predicted values are displayed in Table 5. The experimental values of 7, 14, 28 days specimen under split tensile strength test is shown in Fig 2.

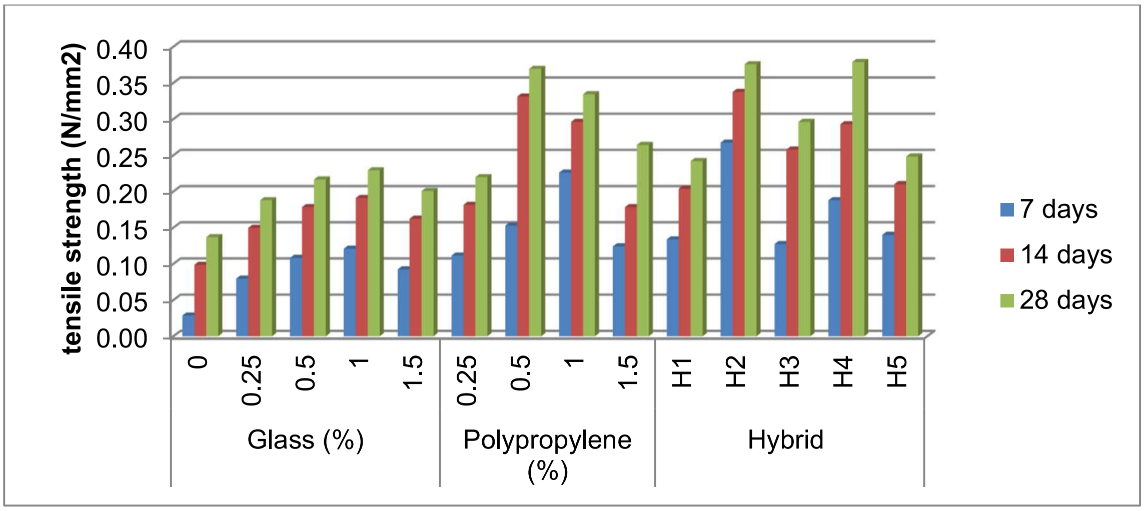

Fig .2- Split tensile strength test results.

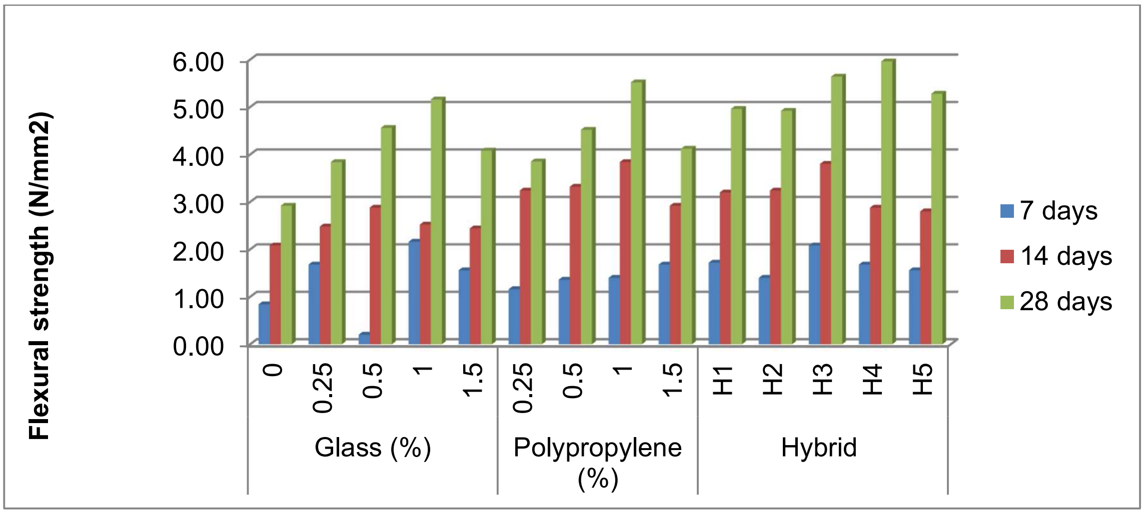

Fig 3 - Modulus of rupture test results.

For glass fiber,
$y = (-3.4303\ V_f^2) + (6.377 \times V_f) + 4.399$ (6)
$R^2 = 0.967$
For polypropylene fiber,
$y = (-1.9417\ V_f^2) + (7.2111 \times V_f) + 5.1704$ (7)
$R^2 = 0.9823$
For hybrid fiber,
$y = (-14.762\ V_g) + (18.454 \times V_p) + 4.911$ (8)
$R^2 = 0.9925$

3.4 Modulus of rupture test

The prism specimens of size (100 x 100x 500) mm are tested under four point loading and gave the results as displayed in table 6. Through regression analysis the equations 9, 10, 11 the predicted values are also displayed in that same table. The experimental values of 7, 14, 28 days specimen under flexural strength test shown in Fig 3.

For glass fiber,
$y = (-6.7565 V_f^2) + (12.244 \times V_f) + 7.135$ (9)
$R^2 = 0.8806$
For polypropylene fiber,
$y = (-9.2044 V_f^2) + (16.967 \times V_f) + 5.6691$ (10)
$R^2 = 0.9062$
For hybrid fiber,
$y = (-10.85 V_g) + (13.581 \times V_p) + 9.8662$ (11)
$R^2 = 0.9703$

3.5 Toughness index

The ability of the concrete to absorb energy during loading and ability to resist crack during loading. The specimen of size (100 x100 x 500) mm of specimen is tested under four point bending testing machine [14]. The equation for calculating the toughness index and Displacement ductility is given in Equ 12 and 13 respectively. Using dial gauge of 0.01mm precision the deflection in the specimen during loading is calculated. Fig 4 shows the area calculated for toughness. A1 is the area under first crack load and A2 is the area under ultimate load. The Table.7 shows the displacement ductility and toughness index values of all the hybrid specimen. The regression equation [15] used for displacement ductility and toughness index is shown in Equ 14 and 15 respectively.

$$\text{Toughness index} = \frac{\text{area under the ultimate load}}{\text{area at the first crack}} \quad (12)$$

Table 7

Toughness of the material graph

Fibers	Mix	% of G fiber	% of PP fiber	Displacement ductility		Toughness index	
				Experimental value	Predicted value	Experimental value	Predicted value
CC	0	-	-	3.21	3.57	1.10	1.359
Hybrid	H1	0.2	0.8	5.38	4.36	3.71	4.09
	H2	0.8	0.2	5.48	5.26	6.39	7.66
	H3	0.5	0.5	4.63	5.2686	5.18	5.88
	H4	0.3	0.7	5.87	5.11	4.29	4.69
	H5	0.7	0.3	4.88	4.51	5.49	7.07

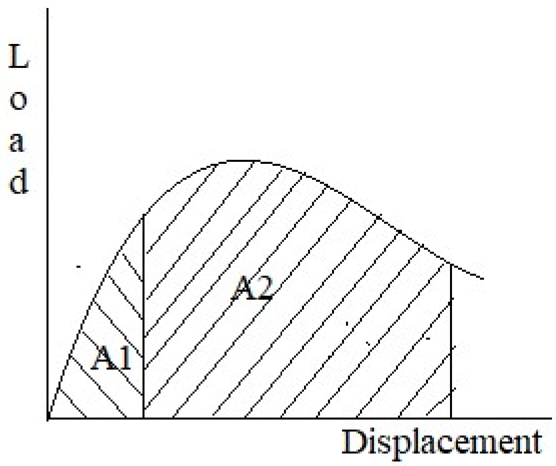

Fig.4 - Toughness index of concrete.

$$\text{Displacement Ductility} = \frac{\text{Ultimate displacement}}{\textit{displacement at yield}} \quad (13)$$

For Displacement ductility calculation, the regression equation obtained is,

$$y = (-0.2708\, V_g) + (1.2412V_p) + 4.3298 \quad (14)$$

$R^2 = 0.8126$

For Toughness index calculation, the regression equation obtained is,

$$y = (0.9V_g) - (5.0551V_p) + 7.9546 \quad (15)$$

$R^2 = 0.9822$

4.Conclusion

Based on the experiments and investigation, the following conclusions are made,

- The characteristic strength of concrete without fiber showed less value than the concrete with fibers.
- The HSC increased the structural integrity of the concrete.
- Therese was 20% increase in toughness index of H4 hybrid fiber concrete than the normal HSC concrete. There was 67% increase in displacement ductility of the H2 concrete than the normal concrete
- The R^2 value was between 0.7 and 0.9, using statistical tools. The predictive values using regression analysis were almost equal to the experimental values.
- The split tensile test and modulus of rupture showed almost similar regression values.
- The properties of the fiber highly contributed for the prediction values.

REFERENCES

[1] S. Eswari, P.N. Raghunath, K. Suguna, Regression modelling for hybrid fiber reinforced concrete. International journal of applied engineering and research, 2008, **3**(9), 1235-1244.

[2] S. Karthiyaini, K. Senthamaraikrishnan, J. Priyadarshini, Kamal Gupta, M. Shanmugasundaram, Prediction of mechanical strength of fiber admixed concrete using mulple regression analysis and artificial neural network. Advances in material science and engineering, 2019.

[3] S. Shrivastava, V.K. Shrivastava, Behavior of Concrete using the Hybrid Fiber with and without Fly Ash, **I**nternational Journal for Innovative Research in Science & Technology, 2018, **4**(9), 2349-6010.

[4] A. Annadurai, A. Ravichandran, Investigations on mechanical properties of hybrid fiber reinforced high strength concrete. International journal of engineering research and technology, 2013, **12**(2), 2439-2447.

[5] A.M. Alhozaimy, P. Soroushian, F. Mirza, Mechanical properties of polypropylene fiber reinforced concrete and the effects of pozzolanic materials. Cement and Concrete Composites, 1996, **18**(2), 85-92.

[6] A.W. Otunyo, and A.J.Odebiyi, Regression modelling of the strength properties of concrete reinforced with polypropylene fiber and alkali resistant glass fiber. Nigerion Journal of tehnology, 2018, **37**(4), 898-906.

[7] A. Ravichandran, K. Suguna, P.N. Ragunath, Strength modelling of high strength concrete with hybrid fiber reinforcement. American journal of applied sciences,2009, **6**(2), 219-223.

[8] S.R. Naraganti, R.M.R. Pannem, J. Putta, Impact resistance of hybrid fiber reinforced concrete containing sisal fibers. Ain shams engineering journal, 2019, **10**, 297-305.

[9] J. Feng, G. Yin, H. Tuo, Z. Niu, Parameter optimization and regression analysis for multi-index of hybrid fiber-reinforced recycled coarse aggregate concrete using orthogonal experimental design. Construction and building materials, 2021, **267**, 1-14.
[10] A. Bernard, E.C. Bosi-Levenbach, E, The plotting of observations on probability paper. Stat. Neederlandica, 1953, **7**, 163–73.
[11] Z. Marcalikova, R. Cajka, V. Bilek, D. Bujdos, O. Sucharda, Determination of mechanical characteristics for fiber reinforced concrete with straight and hooked fibers. Crystals, 2020, **10**(545), 1-21.
[12] V.R. Riley, J.L. Reddaway, Tensile strength and failure mechanics of Fiber composites, Journal of Materials Science, 1968, **3**, 41-46.
[13] N. Banthia, A. Dubey, Measurement of flexural Toughness of Fiber-Reinforced Concrete Using Technique – Part 2: Performance of various Composites, ACI Materials Journal, 2000, **97**(1), 3-11.
[14] B. Barr, R.Gettu, S.K.A. Al-Oraimi, L.S. Bryars, Toughness measurement - the need to think again, Cement and concrete composites, 1996, **18**(4), 281–29.
[15] S. Eswari, S. Kothandaraman, Regression modelling for strength and toughness evaluation of hybrid fibre reinforced concrete. ARPN journal of engineering and applied sciences, 2011, **6**(5), 1-8.

****

ANIVERSĂRI

20 septembrie (1459) – Ziua orașului București

La această dată se împlinesc 562 de ani de la prima atestare documentară a existenței Orașului București, într-un hrisov emis de cancelaria voievodului Vlad Țepeș. În ordine cronologică, orașul București a devenit treptat, în secolele următoare, cea de a patra capitală a Țării Românești a Munteniei (dupa Câmpulung, Curtea de Argeș și Târgoviște) și prima capitală a României Mari după Războiul de Întregire Națională din 1916 – 1918.

****