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Mathematical Modeling of Split Tensile Strength of Agrostone with Different Bio-fillers

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Abstract: There has been a growing imbalance in the demand and supply of construction materials with increasing prices day by day at an alarming rate due to escalating cost of energy. Quest for a low cost, environmental friendly material has resulted in the development of Agrostone made out of industrial and agricultural waste while saving the environment from solid waste disposal issues. This also contributes for saving the energy required for production of conventional building materials up to 20 per cent thereby reducing the emissions. Agrostone made of different bio-fillers such as water hyacinth, bagasse and grass, satisfy the strength requirements as per Ethiopian construction material standard which is equivalent to a hollow block. The split tensile strength has been evolved through the compression test by adopting the standard test methods of applied for concrete. This paper presents the correlation of the experimental results split tensile strength with the values obtained using various empirical relations existing in the literature for unreinforced concrete. It is found that all these relations have underestimated the results while the experimental results of Agrostone with water hyacinth bio-filler have better correlation with results of relation given by Arioglu et al. This paper also presents mathematical models developed using linear and polynomial regression analysis to predict the split tensile strength of Agrostone. The correlation coefficients from the regression analysis are obtained using the Stats.blue software. It is found that the polynomial equations of degree five and the correlation indicators r and r2 show a strong relation between the independent compressive strength and the dependent split tensile strength. The linear regression also predicts the values with acceptable degree of accuracy. The results obtained by developed mathematical models are very close to the experimental within acceptable range of error.

Keywords: Agrostone, sustainable construction material, split tensile strength, regression analysis, green building material

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1. Introduction

Many recent studies describe the fact that over half of the world's population now resides in cities. It is predicted that by 2030, seven of every ten urban residents will be living in either Asia or Africa. Therefore, the African urban transition will have profound and long-lasting impact on the life of a large percentage of the world's population Larsen, L., et al. (2019) As a consequence; many of the African countries will face serious challenges in providing affordable housing to urban dwellers Wibshet T. Z. (2012). Due to rapid growth of population, urbanization and industrialization, the demand for conventional building materials is increasing day by day Aprianti, E. et.al. (2015) and Mangesh, M.V. et al. (2013). Consequently, the world is searching for an alternate building materials to ensure eco-friendly and sustainable development using industrial wastes and agricultural by products. Hence, it has become mandatory to find sustainable, low cost and eco-friendly substitute building materials from locally available sources.

Agrostone is such a green building material that is used to prepare panels from agricultural and industrial waste along with other light-weight natural minerals as fillers and magnesium based chemicals as binders Yonas M. D., (2021). Agrostone panels reduce the cost of wall construction by 50% compared to the conventional building materials Wibshet T. Z. (2012). Further, it also reduces the problem of disposal of huge industrial and agricultural solid waste while saving the environment from pollution and emissions Rauta, S.P. et al. (2011). These Agrostone panels are extensively used in several Ethiopian housing projects for partitions in building interiors Wibshet T. Z. (2012). Inspired by the great potential of Agrostone, the present author has conducted several experimental studies on Agrostone with water hyacinth bio-mass which can be used as a substitute for hollow blocks and meets the Ethiopian building material standards. The current study extends the previous study by evaluating the correlation of compressive and split tensile strength of experimental results with those obtained from empirical relations given by different researchers for non-reinforced concrete. The significant contribution of this paper is the development of linear and polynomial equations from regression analysis of the experimental results to predict the split tensile strength of different Agrostone materials from compressive strength.

2. Literature Review

Classification of concrete in most national and international design codes is often based on compressive strength, while other mechanical properties such as tensile strength, modulus of elasticity and compressive strain are expressed as a function of compressive strength. Due to the complexity, cost and time involved in conducting the tensile test especially for brittle materials, many researchers are interested to predict the tensile strength accurately in a simplified manner. Several theoretical and empirical models have been developed to predict the splitting tensile strength of concrete based on its compressive strength Mutiu, A. et al. (2017). Agrostone is a relatively new material which is brittle, cracks easily under tensile loading and has properties quite different from those of conventional building materials. Consequently, it is crucial to know the tensile strength of Agrostone when it has to be used for tensile load applications. Agrostone is an ideal green building material for internal partition walls, roof ceiling, doors etc.

There are three types of tests used for evaluating the tensile strength of concrete. They are direct tension, flexure and split tensile tests. The tensile strength varies based on the type of test. Due to its high variability, complexity, cost and time-consuming nature of tensile tests, many scientists and engineers suggest to assess this property through compressive strength Mutiu, A. et al. (2017) and Wen-Cheng et al. (2020). A standard test method is required to provide accurate, reproducible, unambiguous, and experimentally viable results. Due to the absence of relevant test standard for Agrostone for estimating its properties, the standard used for concrete is chosen based on the similarity of the brittleness property. Various empirical models developed for concrete materials and available in the literature are used to predict the split tensile strength of various Agrostone materials.

The split tensile test conducted on cylindrical specimen is the simplest and the most reliable method that gives a low coefficient of variation. The cylindrical specimen is loaded in compression diametrically between two plates as indicated in Fig. 1. This loading generates almost uniform tensile stress along the diameter which causes the specimen to fail by splitting along a vertical plane. The split tensile strength (σ_{SP}) can be used to estimate the direct tensile strength (σ_t) by multiplying with a conversion factor of $\lambda = 0.9$ Arıoglu, N. et al. (2006).

According to ASTM (2017), C496/C496M-17, the split tensile stress (σSP) which causes failure of the specimen is given by eq. (1)

$$\sigma_{SP} = \frac{2F}{\Pi D l} \tag{1}$$

where,

σ_{SP} - Split tensile strength, MPa
F - Maximum compressive load applied indicated by the testing machine, N
D - Specimen diameter, mm
l - Specimen length, mm

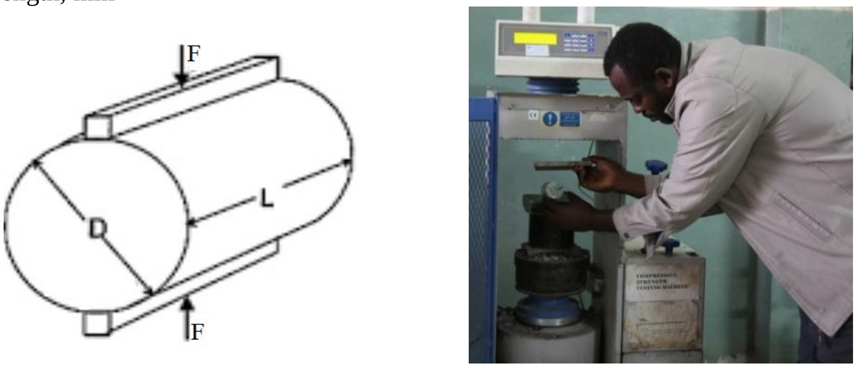


Fig. 1 - Loading on the specimen and testing for split tensile strength

American Concrete Institute (ACI) recommends the square root relationship between split tensile strength and compressive strength. Majority of the relations given by different researchers for predicting the tensile strength of high-strength concrete involve a square root function which is similar to that proposed by ACI. However, the recent studies have indicated that the square root relationship is not appropriate Mutiu, A. et al. (2017). The ACI model overestimates split tensile strength for concrete with compressive strength less than 20 MPa and underestimates for concrete with compressive strength greater than 30 MPa Zaina, M et al., (2002). An empirical relationship between split tensile strength (σSP) and compressive strength (σC) suggested by various researchers Luan, C.,et al (2021), Bin, A. F.,et al (2020) and Jaber, A.,et al (2018) is given by eq. (2)

$$\sigma_{SP} = k\sigma_c{}^n \quad (2)$$

where, k, n-constant coefficients
σ_C - compressive strength of concrete

The coefficients k and n from experimental given by various researchers are given in Table 1.

Table 1 - Coefficients k and n given by various researchers

[Bin, A. F., et al (2020), Jaber, A., et al (2018) Chhorn, C. et al (2018), and Behnood, A. et al (2015)]

Researchers or Institutions	**Constant coefficients**	
	k	**n**
Lavanya and Jegan (2015)	0.249	0.772
ACI Committee 318 (2014)	0.560	0.500
Selim (2008)	0.106	0.948
Arioglu et al.(2006)	0.387	0.630
CEB-FIP Model Code for Concrete Structure (1991)	0.300	0.667
Oluokun et al. (1991)	0.294	0.690
Gardner (1990)	0.330	0.667
Gardner (1988)	0.470	0.590
	0.466	0.660
Raphael (1984)	0.313	0.667
Carino and Lew (1982)	0.272	0.710
Carneiro and Barcellos (1953)	0.340	0.735

3. Materials and Methods

3.1 Materials

The Agrostone composite is developed out of agricultural residue and lightweight minerals like pumice and diatomiteas fillers, Yonas M. D., (2021).. Water hyacinth, bagasse and grass are used as bio-fillers. Bagasse is the fibrous substance left after crushing the sugarcane. Water hyacinth collected from Blue Nile River and dried in direct sunlight for 15 days and further dried in the laboratory drying oven at 105ºC to remove all the contents of the water. Usually it contains about 95.8% of water during harvesting and reduced to 72% after 15 days under average room temperature of 25ºC and 68% humidity. The high moisture content of water hyacinth hinders transportation and processing, Innocent Akendo, C.O. et al. (2017). The average bulk density of chopped water hyacinth, bagasse and grass filler is 138 kg/m3, 402 kg/m^3 and 336 kg/m^3 respectively. The average density of Agrostone made of water hyacinth, bagasse and grass bio-filler is 820 kg/m^3, 885 kg/m^3 and 1160 kg/m^3 respectively, Yonas M. D., (2021).

The binder (sorel cement) is prepared using magnesium oxychloride, a mixture of magnesium oxide (MgO) and with concentrated solution of Magnesium Chloride ($MgCl_2$). Glass fibers cut to 20 mm long are used as reinforcement to increase flexural strength. Pumice, a natural mineral that contains 72% silicon dioxide (SiO_2) that is found in different parts of Ethiopia, is used as filler.

3.2 Methods

3.2.1 Sample Preparation and Testing

Water, magnesium chloride, hydrochloric acid, hydrogen peroxide and caustic soda are mixed in proper proportion to prepare the activated solution and it is kept in mixing chamber until it is activated and ready for use as a binder. Fillers, binder and reinforcement are also added into the activated solution in proportions given in Table 2. All the contents are agitated to get a uniform mix. Samples were prepared for each bio-filler, i.e., water hyacinth bio-filler (Type I), bagasse bio-filler (Type II) and grass bio-filler (Type III). Possibly due to its higher water absorption capacity of water hyacinth, the mix with water hyacinth bio-filler requires 20% extra activated solution, Yonas M. D., (2021).

Table 2 - Mix design for Agrostone samples [Yonas M. D., (2021)]

S.No.	Ingredients	Types of Agrostone		
		Type I	Type II	Type III
1	Activated Solution	1.2 lit	1 lit	1 lit
2	Pumice	160 g	160 g	160 g
3	Magnesium Oxide	860 g	860 g	860 g
4	Glass Fiber (20mm long)	15 g	15 g	15 g
5	Water hyacinth	100 g	-	-
6	Bagasse	-	100 g	-
7	Grass	-	-	100 g

Due to the difficulty in evaluating the tensile strength for brittle materials through direct tensile test, is obtained indirectly by conducting a compressive test on the specimens which is called the split tensile strength. The ASTM (2017), C496/C496M-17 standard used for testing of non-reinforced is considered suitable for testing of Agrostone materials due to the similarity of the brittleness property. Cylindrical specimens of 50 mm diameter and 100 mm long were moulded by manual ramming the mix into the moulds. The samples were removed from the moulds after 48 hours and are exposed to atmospheric curing for 7, 14, 21 and 28 days. Type I, Type II and Type III specimens (four from each) were randomly chosen from the drying table to conduct test for split tensile strength on Universal Testing Machine. The maximum load that can be sustained by the specimen was recorded for further analysis.

3.2.2 Existing Mathematical Model Testing and Development

The values of split tensile strength predicted from experiments results of compressive strength are compared with the values predicted using the empirical relations given by various researchers and the corresponding percentage of errors are furnished in Table 1.

Subsequently, the linear and polynomial regression analysis is carried out using stats.blue software to develop elegant mathematical models which can express the split tensile strength more accurately for the Agrostone materials with different bio-fillers.

3.3 Tools and Equipment

Digital mass balance with precision of 0.001gram is used to measure different ingredients of the solution and the prepared specimens. A graduated measuring cylinder of 1 ml accuracy is used to measure the liquid chemicals and water. A mixing machine with rotating speed range of 0 - 60 RPM is used along with a spiral type agitator. A piece of PVC pipe was used as a mould. Scissor and knife, Vernier calliper, thermometer, and hygrometer are used for cutting the fibers, measuring length, temperature, and humidity respectively. The bio-fillers are dried in oven. A semi-automatic Universal Testing Machine, 6.8 kN loading capacity having a display unit is used for conducting the split tensile strength of the specimens.

4. Results and Discussion

The split tensile strength is obtained by testing four specimens selected randomly for each type for a given curing time ensuring that the variation of the strength will not exceed by ± 5 percent. The strength values for different Agrostone materials are presented in Table 3.The results are arranged in ascending order to obtain a uniform pattern of plots between compressive and split tensile strength. The strength of Type II and Type III Agrostones has decreased after 21st days which can be observed in Fig. 3. This is due to the increase in moisture content of the specimens, Yonas M. D., (2021). The average values of split tensile strength for different curing times are given in Table 4.The values of compressive strength are taken from the experimental results published by the author Yonas M. D., (2021) and they are used to correlate the split tensile strength obtained from various empirical formulas given in Table 1.

Table 3 - Strength of Agrostone with different bio-fillers

Type I-Water Hyacinth		Type II–Bagasse		Type III-Grass	
Compressive Strength [MPa]	Split Tensile Strength [MPa]	Compressive Strength [MPa]	Split Tensile Strength [MPa]	Compressive Strength [MPa]	Split Tensile Strength [MPa]
4.996	1.050	5.430	1.503	7.222	1.760
5.002	1.101	5.719	1.436	7.434	1.622
5.018	1.100	5.799	1.511	7.604	1.667
5.163	1.105	5.852	1.533	7.729	1.805
5.262	1.112	5.904	1.602	7.963	1.832
5.340	1.113	6.282	1.648	8.334	1.853
5.464	1.124	6.301	1.699	8.769	1.880
5.512	1.132	6.320	1.776	8.814	1.888
5.544	1.141	6.391	2.008	8.935	1.920
5.575	1.141	6.592	2.051	9.041	1.932
5.813	1.142	6.877	2.136	9.139	1.946
5.993	1.151	6.975	2.153	9.257	1.960
6.017	1.220	7.017	2.179	9.299	2.063
6.400	1.291	7.175	2.209	9.371	2.119
6.590	1.312	7.617	2.248	9.402	2.174
6.593	1.314	7.770	2.262	9.664	2.188

Table 4 - Average split tensile strength

Curing time-days	Split Tensile Strength of Agrostone[MPa]		
	Type I	Type II	Type III
7	1.09	1.51	1.83
14	1.11	1.68	2.13
21	1.16	2.20	1.94
28	1.21	2.11	1.75

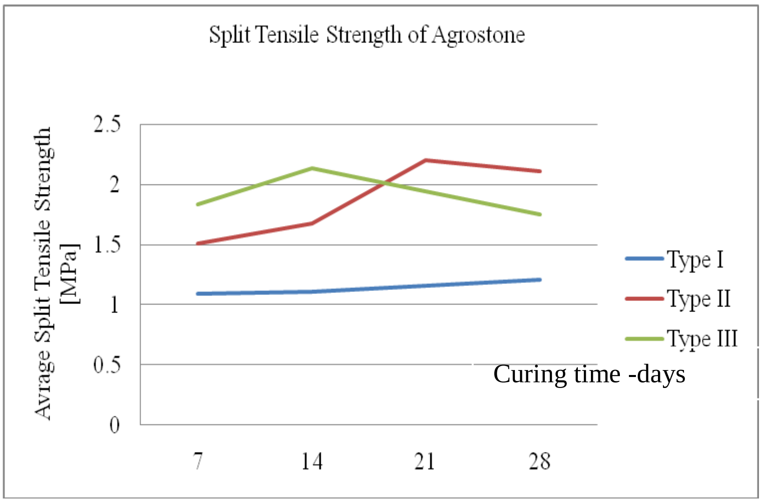


Fig. 3 - Average split tensile strength of different Agrostone materials

The compressive and tensile test specimens were made of the same mix. The average values of split tensile strength calculated using the empirical formulas are given in Table 5. The results obtained from these formulas are mostly on the lower side as these formulas correspond to non-reinforced concrete.

Table 5 - Predicted average split tensile strength of different of Agrostone materials

Agrostone Type	Curing Age [Days]	Measured Compressive Strength [MPa]	Measured Split Tensile Strength [MPa]	Predicted Split Tensile Strength [MPa]											
				Lavanya and Jegan (2015)	ACI Committee 318 (2014)	Selim (2008)	Arioglu et al. (2006)	Oluokun et al. (1991)	CEB-FIB (1991)	Gardner (1990)	Raphael (1984)	Carino and Lew (1982)	Carneiro and Barcellos (1953)	Gardner (1988)	Gardner (1988)
				$\sigma_{sp} = 0.249\sigma_c^{0.50}$	$\sigma_{sp} = 0.56\sigma_c^{0.5}$	$\sigma_{sp} = 0.106\sigma_c^{0.948}$	$\sigma_{sp} = 0.387\sigma_c^{0.63}$	$\sigma_{sp} = 0.294\sigma_c^{0.69}$	$\sigma_{sp} = 0.3\sigma_c^{0.667}$	$\sigma_{sp} = 0.33\sigma_c^{0.667}$	$\sigma_{sp} = 0.313\sigma_c^{0.667}$	$\sigma_{sp} = 0.272\sigma_c^{0.71}$	$\sigma_{sp} = 0.34\sigma_c^{0.735}$	$\sigma_{sp} = 0.47\sigma_c^{0.59}$	$\sigma_{sp} = 0.466\sigma_c^{0.66}$
Type I	**7**	5.26	1.09	0.897	1.284	0.511	1.101	0.924	0.908	0.999	0.947	0.884	1.152	1.252	1.394
	14	5.34	1.11	0.907	1.294	0.519	1.112	0.934	0.917	1.009	0.957	0.894	1.165	1.263	1.408
	21	5.52	1.16	0.931	1.316	0.535	1.135	0.956	0.938	1.031	0.978	0.915	1.193	1.288	1.439
	28	6.40	1.21	1.044	1.417	0.616	1.246	1.058	1.035	1.138	1.080	1.016	1.330	1.405	1.587
Type II	**7**	5.73	1.51	0.958	1.340	0.555	1.162	0.981	0.961	1.053	1.003	0.939	1.227	1.316	1.475
	14	6.32	1.68	1.034	1.408	0.609	1.236	1.049	1.103	1.129	1.070	1.007	1.318	1.395	1.573
	21	6.78	2.20	1.091	1.458	0.651	1.292	1.101	1.075	1.183	1.122	1.059	1.388	1.454	1.648
	28	7.17	2.11	1.139	1.500	0.686	1.339	1.145	1.116	1.228	1.165	1.101	1.446	1.503	1.710
Type III	**7**	7.63	1.83	1.195	1.547	0.728	1.392	1.195	1.163	1.280	1.214	1.151	1.514	1.559	1.782
	14	8.34	2.13	1.280	1.617	0.792	1.472	1.270	1.235	1.358	1.288	1.226	1.616	1.643	1.889
	21	9.16	1.94	1.376	1.695	0.865	1.562	1.355	1.314	1.446	1.371	1.311	1.732	1.736	2.010
	28	9.37	1.75	1.401	1.714	0.884	1.585	1.377	1.334	1.468	1.392	1.332	1.761	1.760	2.040

Table 6 - Percentage error predicted for split tensile strength of different Agrostone materials

Bio-filler Type	Curing time [days	Average Measured Compressive Strength [MPa]	Average Measured Split Tensile Strength [MPa]	Prediction Error [%] of Average Split Tensile Strength											
				Lavanya and Jegan (2015)	ACI Committee 318 (2014)	Selim (2008)	Arioglu et al. (2006)	Oluokun et al. (1991)	CEB-FIB (1991)	Gardner (1990)	Raphael (1984)	Carino and Lew (1982)	Carneiro and Barcellos (1953)	Gardner (1988)	Gardner (1988)
				$\sigma_{sp} = 0.249\sigma_c^{0.50}$	$\sigma_{sp} = 0.56\sigma_c^{0.5}$	$\sigma_{sp} = 0.106\sigma_c^{0.948}$	$\sigma_{sp} = 0.387\sigma_c^{0.63}$	$\sigma_{sp} = 0.294\sigma_c^{0.69}$	$\sigma_{sp} = 0.3\sigma_c^{0.667}$	$\sigma_{sp} = 0.33\sigma_c^{0.667}$	$\sigma_{sp} = 0.313\sigma_c^{0.667}$	$\sigma_{sp} = 0.272\sigma_c^{0.71}$	$\sigma_{sp} = 0.34\sigma_c^{0.735}$	$\sigma_{sp} = 0.47\sigma_c^{0.59}$	$\sigma_{sp} = 0.466\sigma_c^{0.66}$
Type I	7	5.26	1.09	-21.52	15.11	-113.31	1.00	-17.96	-20.04	-9.11	-15.10	-23.30	5.38	12.94	21.81
	14	5.34	1.11	-22.38	13.95	-113.87	0.18	-18.84	-21.05	-10.01	-15.99	-24.16	4.72	12.11	21.16
	21	5.52	1.16	-24.60	11.85	-116.82	2.20	-21.34	-23.67	-12.51	-18.61	-26.78	2.77	9.94	19.39
	28	6.40	1.21	-15.90	14.61	-96.43	2.89	-14.37	-16.91	-6.32	-12.04	-19.09	9.02	13.88	23.75
Type II	7	5.73	1.51	-46.03	-7.24	-172.07	-22.17	-43.95	-36.90	-33.75	-41.12	-49.95	-14.57	-8.24	4.00
	14	6.32	1.68	-62.48	-19.32	-175.86	-35.92	-60.15	-52.31	-48.80	-57.01	-66.83	-27.47	-20.43	-6.80
	21	6.78	2.20	-101.65	-50.89	-237.94	-70.28	-99.82	-104.65	-85.97	-96.08	-107.74	-58.50	-51.31	-33.49
	28	7.17	2.11	-85.25	-40.67	-207.58	-57.58	-84.28	-89.07	-71.82	-81.11	-91.64	-45.92	-40.39	-23.39
Type III	7	7.63	1.83	-53.14	-18.29	-151.37	-31.46	-53.14	-57.35	-42.97	-50.74	-58.99	-20.87	-17.38	-2.69
	14	8.34	2.13	-66.41	-31.72	-168.94	-44.70	-67.72	-72.47	-56.85	-65.37	-73.74	-31.81	-29.64	-12.76
	21	9.16	1.94	-40.99	-14.45	-124.28	-24.20	-43.17	-47.64	-34.16	-41.50	-47.98	-12.01	-11.75	3.48
	28	9.37	1.75	-24.91	-2.10	-97.96	-10.41	-27.0	-31.18	-19.21	-25.72	-31.38	0.62	0.57	14.21

$$\text{percentage error} = \frac{\text{Predicted value} - \text{Measured value}}{\text{Predicted Value}} x100 \quad (3)$$

The percentage error between the predicted and the measured values is given by eq. (3). The results in Table 6 show that the split tensile strength predicted by most of the empirical relations is below the measured value. The ACI model overestimates split tensile strength since the compressive strength of the Agrostones (Type I, II and III) is less than 20 MPa, Zaina, M.F.M., et al (2002). This holds true for Type I Agrostone while for types the ACI model underestimates the split tensile strength. The empirical formula developed by both Arioglu et al. and Carneiro and Barcelloshas a better prediction for Type I. The formula developed by Arioglu et al. gives the values close to the measured values with deviation less than 2%. Since the empirical formulas developed for concrete are not appropriate for other types of Agrostone materials. Hence, it is required to develop individual equation to predict the split tensile strength of each Agrostone material since the equations available for concrete could not provide reasonable results. The regression analysis helps in developing the mathematical model as there is no direct relation between the compressive strength and split tensile strengths. Linear and polynomial regression analysis is conducted and the coefficients are compared to evaluate the level of accuracy of each model. The linear regression equation has the form indicated in eq. (4) and the polynomial regression equation has the form given in eq. (5):

$$Y = \beta X + \beta y \quad (4)$$

$$Y = \beta_5 X^5 + \beta_4 X^4 + \beta_3 X^3 + \beta_2 X^2 + \beta_1 X + \beta_0 \quad (5)$$

Where,

Y- dependent variable

X - independent variable

β - slope of the line

βy - is y intercept

β_0 - constant

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ – coefficients

Linear regression equation is relatively simple with a constant slope whereas the slope for polynomial regression equation varies along the curve. The interpretation of the coefficients for linear relationship is much easier compared to those of a curvilinear relationship.

Polynomial regression is better for fitting the data than linear regression and also the root mean square error (RMSE) lower than that of linear regression. The r2 values indicate the coefficient of determinations. These values explain the extent of variability of one factor over another factor. Its value ranges between 0 and 1. While 1 indicates a perfect fit, and a highly reliable model for forecasts, while 0 indicates failure of the model in accurately predicting the scenario. Consequently, higher r2 value indicates a strong relationship between the dependent and independent variables.

The determination coefficient is calculated using eq. (6) Zaina, M.F.M., et al (2002) and Chithra, S.,et al. (2016)

$$r^2 = 1 - \frac{\text{Sum of squares of residuals}}{\text{Sum of squares of predicted values}} \quad (6)$$

In the present study, the coefficients of regression are calculated by considering 95% confidence level with an error level limited to five percent. Input variables with p -value less than 0.05 can only be considered to be significant. Stats.blue software is used to conduct the regression analysis for obtaining the equations, the plots, parameters of relations between compressive strength and split tensile strength of different Agrostone materials.

The software provides the correlation indicator for the equation once the data is fed and the software is run. The equations of regression analysis obtained are given in Table 7.

Table 7 - Regression models for Agrostone with different bio-fillers

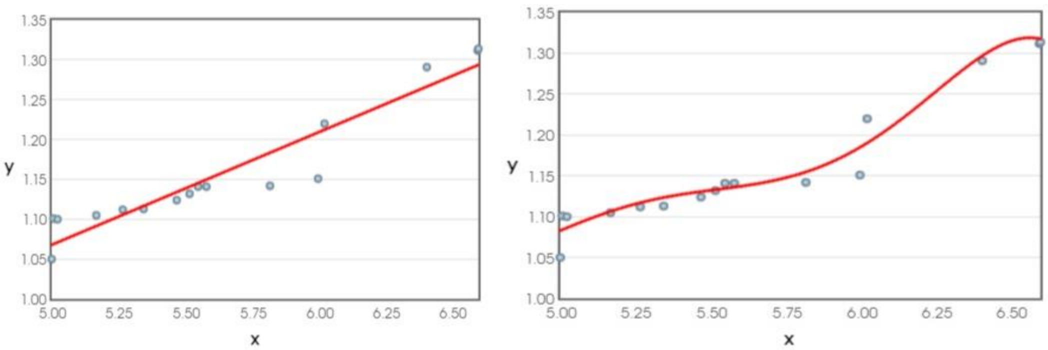
Type-biofiller	Type of regression	Developed regression model	Correlation indicator		
			r	r^2	r^2 adj
Type I Water hyacinth	Linear	$\sigma_{SP} = 0.141\ \sigma_C + 0.361$	0.952	0.906	-
	Polynomial	$\sigma_{SP} = -0.226\sigma_C^5 + 6.318\sigma_C^4 - 70.321\sigma_C^3 + 389.742\sigma_C^2 - 1075.666\sigma_C + 1183.736$	-	0.958	0.943
Type II Bagasse	Linear	$\sigma_{SP} = 0.425\ \sigma_C - 0.893$	0.947	0.897	-
	Polynomial	$\sigma_{SP} = 0.187\sigma_C^5 - 6.045\sigma_C^4 + 77.498\sigma_C^3 - 493.481\sigma_C^2 + 1561.157\sigma_C - 1962.398$	-	0.961	0.946
Type III	Linear	$\sigma_{SP} = 0.192\sigma_C + 0.254$	0.929	0.864	-

Grass	Polynomial	$\sigma_{SP} = -0.164\sigma_C^5 + 6.879\sigma_C^4 - 115.216\sigma_C^3 + 961.283\sigma_C^2 - 3994.918\sigma_C + 6617.025$	-	0.967	0.955

The determination coefficients obtained by linear regression for Type I, Type II and Type III materials are 0.906, 0.897 and 0.864 respectively while for polynomial regression, they are 0.958, 0.961 and 0.967 respectively. These coefficients are noted to be higher for polynomial regression. This is due to the higher correlation indicator (r2) for the polynomial regression which indicates a highly reliable model.

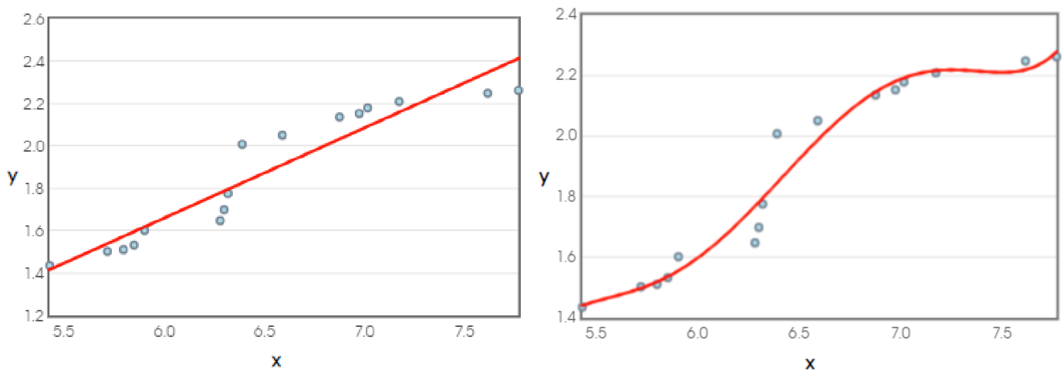
Since the determination coefficient alone cannot validate the model and therefore it has to be combined with p-value and a p-value less than 0.05 is typically considered to as statistically significant, in which case the null hypothesis should be rejected. The p-value greater than 0.05 is the probability that the null hypothesis is true and consequently, the deviation from the null hypothesis is not statistically significant, and the null hypothesis is not rejected. In case, if none of the p-values of the variables obey the stated condition, the model is considered to be inappropriate. During the analysis of polynomial regression degree two and above is considered. While increasing the degree of the polynomial from degree two to degree five, the values of r2 and p-values holds true up to degree five and for degree six and above then the coefficient of determination will not meet the assumption. For polynomial equation of beyond degree five, the p-tests will not hold true and is not applicable.

The goodness of fit measures the distance between a fitted line and all of the data points that are scattered in the diagram. The tight set of data will have a regression line that is close to the points and have a higher level of fit. Plotted using stata.blue software show the degree of closeness of data with the curves. Actual data and the curves predicted by the regression model for different cases of materials and regressions models are indicated in Fig. 5 to Fig. 7. The curves for polynomial regression are more close to the data points compared those of linear regression.



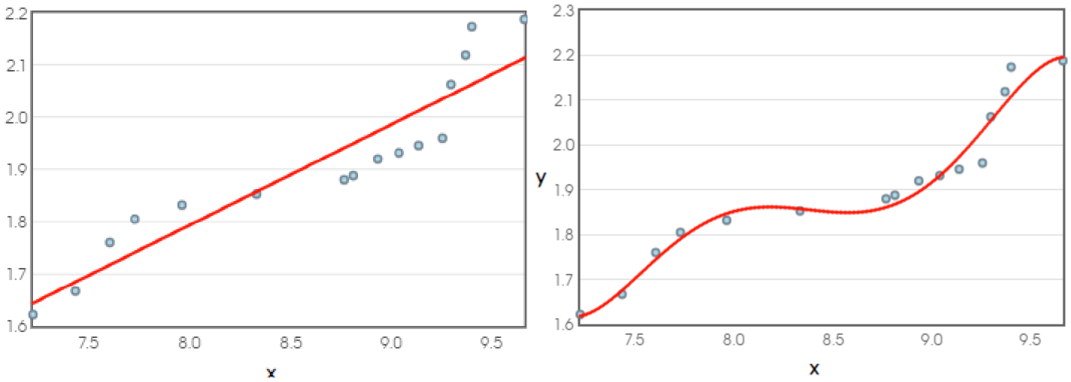
a) Linear regression **b) Polynomial regression**

Fig. 5 - Plot of regression models for Agrostone made of water hyacinth bio-filler



a) Linear regression **b) Polynomial regression**

Fig. 6 - Plot of regression models for Agrostone made of bagasse bio-filler



a) Linear regression **b) Polynomial regression**

Fig. 7 - Plot of regression models for Agrostone made of grass bio-filler

5. Conclusion

The split tensile strength of the three types of Agrostone made of water hyacinth, bagasse and grass bio-filler is found to increase with increase in curing time. The split tensile strength predicted by the existing empirical relations of unreinforced concrete is lower than the experimental results. Mathematical models developed in this paper which are based linear and polynomial regression analysis are more elegant and predict the split tensile strength with higher degree of accuracy. The polynomial regression equations can predict more accurately involving higher complexity while equations by linear regression can be used for preliminary prediction.

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