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RESEARCH ARTICLE

PREDICTION OF MECHANICAL PROPERTIES OF THE CONCRETE/CEMENT MORTAR MADE OF RECYCLED COARSE AND FINE AGGREGATES FROM THEIR CHEMICAL COMPOSITION

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ABSTRACT

The non-destructive tests on concrete with certain limitations used in accessing the limited properties of the concrete, and on cement mortar mass as of date there are no non destructive site test for assessing its strength parameters. To address these issues, a mathematical model was developed in predicting the mechanical properties of concrete Viz., compressive strength, tensile strength, split tensile strength, Impact strengths, shear strength, elasticity modulus, and in Cement mortar the model will be used in predicting the strength parameters of cement mortar. The statistical model of regression technique was employed on the concrete made of different types of aggregates i.e. a set of concrete prepared with that of conventional aggregates, the other set made of untreated recycled coarse and fine aggregates, and the final set made of treated (densified) coarse and fine recycled aggregates, the details of the chemical composition were obtained by processing the different concrete /mortar mass through XRD. Further regression methods were also employed in predicting the mechanical properties of the concrete /mortar mass from the chemical composition of the aggregate mass used in its preparation. The so developed mathematical model found to be an effective tool in assessing the condition of concrete /mortar mass from its chemical composition.

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INTRODUCTION

The whole world is dependent on the non-destructive testing methods such rebound hammer tests, ultra sound pulse velocity tests etc in evaluating the strength of the new/old concrete structures which is with certain assumptions and in ideal conditions, the assumptions fail to comply with the actual site requirements, this reduces the efficacy of the data collected for the said purpose. The alternative method needs to be created to reduce the above difficulties; one of the best methods of evaluating the non-destructive way of assessing the mechanical properties is by knowing the chemical composition of the concrete/mortar mass under study. The various properties of any material depends on the chemical constituents of it, the presence of certain chemicals will contribute to improving the properties and certain chemicals formation will have an adverse effect on the physical and mechanical properties, taking these factors into consideration, an process has been initiated to establish a relation between the mechanical properties of the concrete and its chemical compositions and a part of this a detailed statistical method of analysis has been adopted.

Further, a more stress has been laid in predicting the properties of the concrete and mortar made with recycled coarse and fine aggregates directly by accessing the chemical composition of the recycled coarse and fine aggregate mass. Earlier many researchers [1] have been done in predicting the compressive strength on the concrete prepared with conventional aggregates and limited studies where done on concrete/mortar mass prepared with recycled coarse and fine aggregates, especially the aggregates with untreated and treated recycled demolished concrete aggregates .The research work undertaken helps in providing an in-detail information of the chemical constituents formed in its reaction with cement. Thus with the said goal, the objective of the work is defined accordingly.

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Objectives of the work

- To evaluate the chemical constituents'/composition of the different concrete/mortar mass prepared for the study.
- To study the effect of the chemical composition on the properties of the concrete/mortar mass
- To evaluate the chemical composition of the untreated and treated recycled demolished concrete coarse and fine aggregates and establishing a relation between the mechanical properties of the concrete/mortar mass prepared with these types of aggregates and with their chemical composition.
- To study the role played by the recycled coarse and fine demolished aggregates in the concrete/mortar mass.

Statistical Analysis: Using statistical analysis of laboratory test data from concrete/mortar samples made with different types of aggregates of known chemical composition, regression models were developed to predict the concrete/mortar mass mechanical properties. The regression model(Regression analysis is a set of statistical methods used for the estimation of relationships between a dependent variable and one or more independent variables Independent Variable An independent variable is an input) used for above analysis is curvilinear regression. Curvilinear regression **(**Curvilinear regression makes use of various transformations of variables to achieve its fit) analysis fits curves to data instead of the straight lines you see in linear regression. Technically, it's a catch all term for any regression that involves a curve. For example, quadratic regression and cubic regression.

Concept of Curvilinear Regression: The concept of curved (more exactly, curvilinear) regression is the same as the simple regression throughout, except that the form of the model is not restricted to a straight line. It can now generally refer to the regression curve, which includes the straight line as a subordinate case. Model forms were considered at some length. The most frequently used curves are the parabola, which is like a simple regression with an x^2 term added, and the logarithmic and exponential curves, which are like a simple regression with the x term replaced by a log x or e^x term.

Curvilinear to Multiple Regressions Relationship: The mathematics for curvilinear regression is similar to that for multiple regressions. Suppose we want to develop a quadratic model (a model based on x^2). We start with a univariate straight-line regression (y predicted by x_1). Instead of adding a second variable (y predicted by x_1 and x_2) as in multiple regressions, we use the square of the 1st variable in the position of the 2nd (y predicted by x_1 and x_1^2). Curvilinear regression may be thought of as a special case of multiple regressions. In this regression, we add different powers of the **X** variable ($\mathbf{X}$, $\mathbf{X}^2$, $\mathbf{X}^3$…) to an equation to see whether they increase the $\mathbf{R}^2$ significantly. First you do a linear regression, fitting an equation of the form $\hat{\mathbf{Y}}=\mathbf{a}+\mathbf{b_1X}$ to the data. Then you fit an equation of the form $\hat{\mathbf{Y}}=\mathbf{a}+\mathbf{b_1X}+\mathbf{b_2X^2}$, which produces a parabola, to the data. The $\mathbf{R}^2$ will always increase when you add a higher-order term, but the question is whether the increase in $\mathbf{R}^2$ is significantly greater than expected due to chance.

Next, you fit an equation of the form $\hat{Y}=a+b_1X+b_2X^2+b_3X^3$, which produce an S-shaped line, and you test the increase in $\mathbf{R}^2$. You can keep doing this until adding another term does not increase $R^{\mathbf{2}}$ significantly, although in most cases it is hard to imagine a meaning for exponents greater than 3. Once you find the best-fitting equation, you test it to see whether it fits the data significantly better than an equation of the form $\mathbf{Y}=\mathbf{a}$; in other words, a horizontal line. Even though the usual procedure is to test the linear regression first, then the quadratic, then the cubic, you don't need to stop if one of these is not significant. For example, if the graph looks U-shaped, the linear regression may not be significant, but the quadratic could be.

Input Data: The model that is chosen dictates the inputs. Basically we have a y (Dependent variable) depending on some function of x(Independent variable). We just substitute x- and y-values in the forms given by the model. Where y appears, y-values are put in; where x^2 appears, x-values are squared and those squares put in; where ln(x) appears, logarithms of x-values are found and put in; and so forth.

Process of the Analysis: Because the curvilinear regression is one of the forms of multiple regression, the solution, interpretation, stepwise approaches, and treatment of nominal variables will be the same as in the case of linear regression, with some subscripts changed to superscripts, for example, x2 replaced by x2.

EXPERIMENTAL WORK

With an intention of the cent percentage utilization of recycled demolished coarse and fine aggregates in concrete/mortar preparations. The tests were done in the laboratory, on recycled demolished concrete coarse and fine aggregate with various surface modification and surface treatments viz., Densification, Hydrophobization, Polymerization and a combination of Densification and Polymerization and on treated aggregates physical properties have been evaluated and on the improved properties the best combination has been selected and on these combinations, the concrete /mortar specimens has been cast and tested for its compressive.

Based on the test results it was found that a densification process of surface treatment method is effective in improving the properties of the aggregates and the concrete/mortar mass prepared i.e., a final combination of 2.5% of lithium silicate treatment on a recycled demolished concrete coarse aggregate and 1% colloidal silica dioxide treatment on demolished concrete fine aggregate found to be the best treatment for its usage in concrete and 1% colloidal silica treatment on recycled fine aggregate in its usage in preparation of cement mortar. The test values of compressive strength on cement mortar are depicted in figure 1. Table 01 depicts the Mix design adopted on concrete samples.

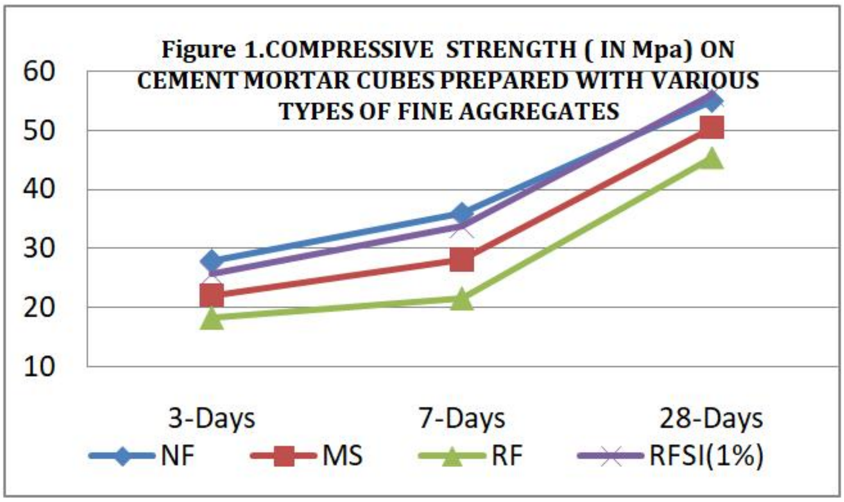


Figure 1.COMPRESSIVE STRENGTH (IN Mpa) ON CEMENT MORTAR CUBES PREPARED WITH VARIOUS TYPES OF FINE AGGREGATES

Table 01. M30 Grade Concrete Mix Design Using Different Types of Coarse and Fine Aggregates

Final Proportion of materials at the site	NCA+NFA	NCA+M-Sand	RCA+RFA	RCA(2.5%LI)+RFA(1%SI)
Water(ltr)	161.278	176.65	210.14	223.98
Cement(Kg)	350.22	350.22	350.22	437.77
Chemical Admixture(ltr)	2.98	2.98	2.98	0
Fine Aggregate(kg)	698.865	688.57	536.7	613.94
Coarse Aggregate(kg)	1190.72	1190.72	1152.94	1179.57

MECHANICAL PROPERTIES EVALUATION ON HARDENED CONCRETE:

On a final combination of 2.5% of lithium silicate treatment on recycled demolished concrete coarse aggregate and 1% colloidal silica dioxide treatment on demolished concrete fine aggregate to test it mechanical properties on concretes a set of cubes, cylinders and prisms were casted and tested for compressive strength, split tensile strength, flexural strength, shear strength impact strength, and for stress strain analysis. And the same were compared with that of cubes casted with Natural Coarse and fine aggregates and also with treated and untreated recycled demolished coarse and fine concrete aggregate .The results on the same are graphically presented at Figures 2,3,4.All the mechanical properties on hardened concrete prepared with treated recycled demolished concrete coarse and fine aggregates have shown improved performance as compared with that of concrete made of untreated recycled aggregates,

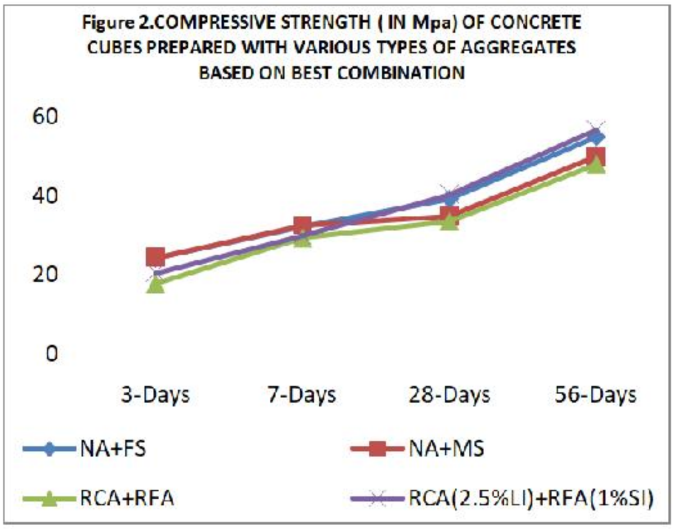


Figure 2.COMPRESSIVE STRENGTH (IN Mpa) OF CONCRETE CUBES PREPARED WITH VARIOUS TYPES OF AGGREGATES BASED ON BEST COMBINATION

XRD Analysis: Mineralogical composition of aggregate, concrete & mortar mass have been determined on few grams of the sample using a diffract meter with Co-Ka radiation anticathode. XRD diffraction is a powerful tool in identification of the mineralogical crystal composition, crystal structure and its internal behavior. Mainly the XRD is done to identify the following parameters.

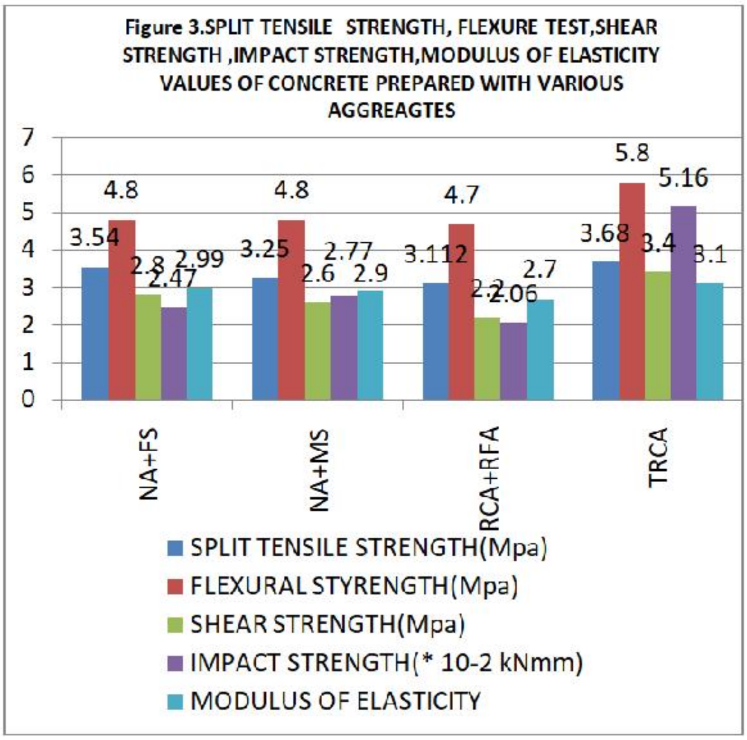


Figure 3.SPLIT TENSILE STRENGTH, FLEXURE TEST,SHEAR STRENGTH ,IMPACT STRENGTH,MODULUS OF ELASTICITY VALUES OF CONCRETE PREPARED WITH VARIOUS AGGREAGTES

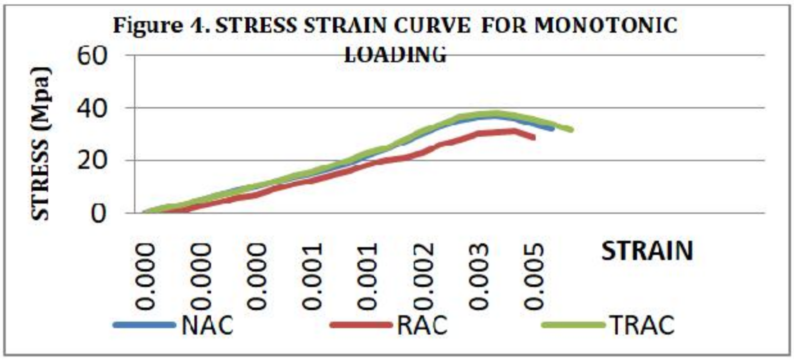


Figure 4. STRESS STRAIN CURVE FOR MONOTONIC LOADING

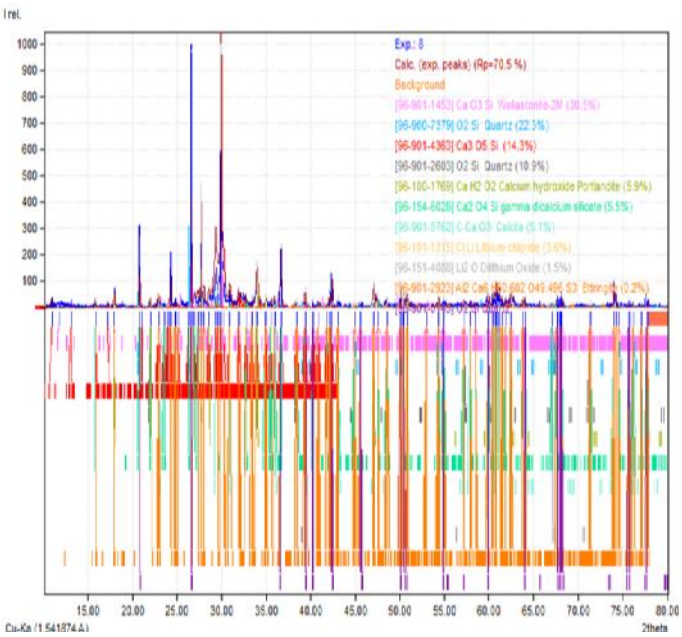


Figure. 5 diffraction pattern graph of concrete specimen prepared with treated recycled demolished concrete coarse and fine aggregates

Phase Identification and its Quantity: The diffraction pattern for every phase is as unique as our fingerprint. Phases with the same chemical composition can have drastically different diffraction patterns.

Use the position and relative intensity of a series of peaks to match experimental data to the reference patterns in the database. The phase identification has been done by using the XRD data and by using Match software and details of which are depicted at Figure 5,6 for concrete/mortar mass prepared with treated aggregates. The Match software helps is assessing the formation of % of Chemical compound formed from the XRD diffraction data and the data gathered on different specimen, the details of the same shown in Figure 5,6.

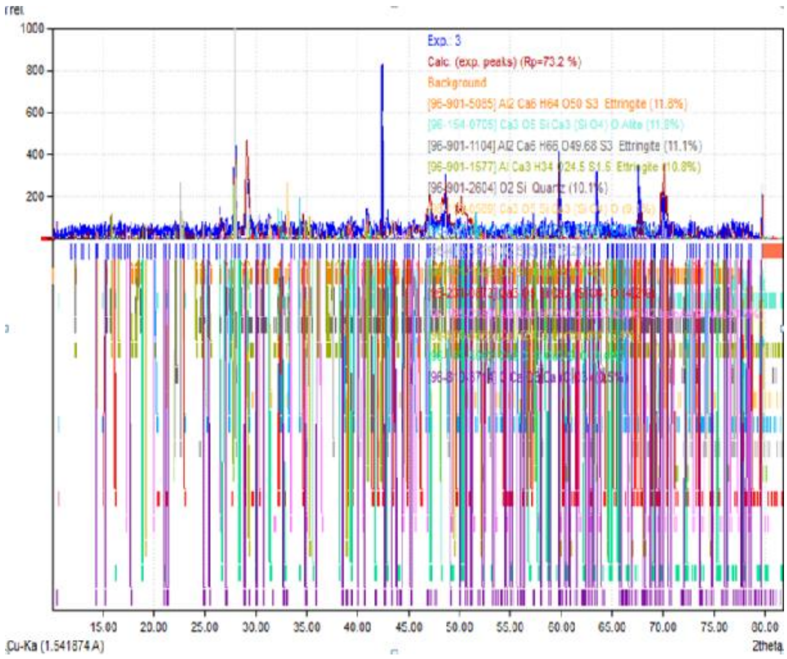


Figure. 6 Diffraction pattern graph of cement mortar prepared with treated recycled demolished concrete fine aggregate

STASTICAL ANALYSIS

As defined in the Introduction the curvilinear regression method is adopted to predict the mechanical properties of the Concrete/Cement Mortar mass from their chemical composition. The initial step is the categorization of dependent and independent variables and in the present case the dependent variable is mechanical properties and independent variables are chemical constituent of the material under study. The dependent variable being single it is categorized as "y" and independent variable being multiple; they are categorized as "x_1, x_2, x_3...x_n". The following basic equation is used to establish it between variables,

General form y = f(x, β), β= Increment effect of x

e.g., $y= \beta_0 x_0+ \beta_1 x_1+ \beta_2 x_2+ \beta_3 x_3+.........+ \beta_n x_n$

Since the case under study consist of more number of independent variables, The impact of the independent variable under each head on dependent variable has been done by calculating mean contribution of independent variable over the dependent variable, and for each independent and dependent variable , the curve fitting methods are used in excel. to find the best value of R^2,and based on the best value of R^2 the relationship has been established for each set and finally the sets are summed by to get the exact relation between the single dependent variable and with multiple independent variable. The above procedure is repeated to find the compressive strength, split tensile strength, flexural strength, shear strength and impact strength by knowing the chemical composition of the concrete mass understudy, similar the relationship of compressive strength of the Mortar mass was established from the chemical constitutes of the mortar mass .Further an attempt has been made to establish the relation between the compressive strength and the chemical constitutes of the aggregates using the curvilinear regression method. The readily available hand held spectroscopy instruments are helpful in finding the insitu chemical composition and the mathematical models developed helps us in having an idea of mechanical properties of the mass under study.

Mathematical Model of Predicting Mechanical Properties of Concrete from its Chemical Composition

Predictive Model for Compressive Strength: The Curvilinear regression method is employed on data gathered from concrete prepared with different types of the aggregates i.e. compressive strength and chemical composition details. The details of compressive strength are obtained from Figure 2 and Chemical composition details of concrete are obtained from XRD diffraction data. The detail step wise regression is as illustrated below,

Thus Overall Compressive Strength(y) based on its Chemical Composition from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5 $y=\{658.302+0.262x_1-0.002x_1^2+0.083x_2-0.014x_2^2-32.15x_3+0.406x_3^2+0.243x_4-0.018x_4^2-0.129x_5+0.002x_5^2\}$

y(Compressive Strength in Mpa) = { 658.302 + 0.206(% of Alite) - 0.002(% of Alite)^2 + 0.083(% of Ettringite) - 0.014(% of Ettringite)^2 - 32.15(% of Quartz) + 0.406((% of Quartz)^2 +0.243(% of Calcite)-0.018(% of Calcite)^2 - 0.129(% of Portlandite) + 0.002(% of Portlandite)^2 }

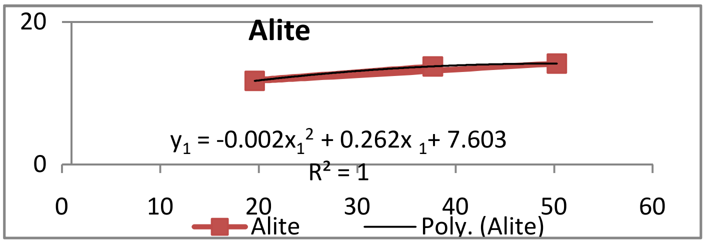
Figure 7. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Compressive Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates.

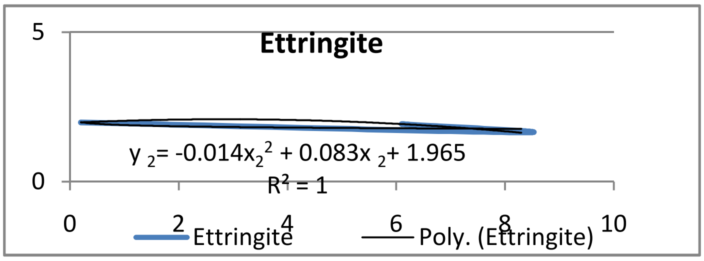
a). Chemical Composition and Compressive strength of different types of concrete

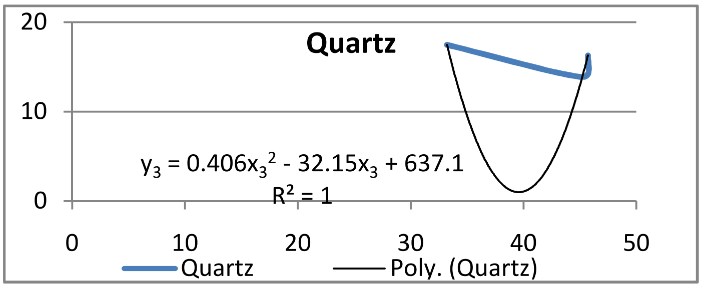
Type of Concrete	CCC(Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
(CC)	39.33	37.7	6.1	45.7	3.6	6.9
(RAC)	33.55	19.6	8.3	45.2	13.5	13.4
(TRAC)	40.44	50.3	0.2	33.2	5.1	5.9

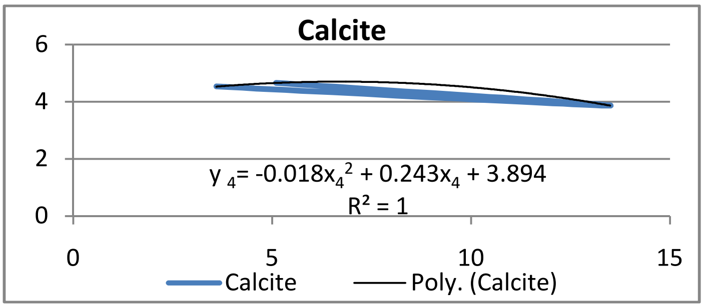
Conventional Concrete(CC), Concrete Prepared with Untreated Recycled Coarse and Fine Aggregates (RAC), Concrete Prepared with Treated Recycled Coarse and Fine Aggregates (TRAC). Compressive Strength of Concrete at 28-days(Mpa)-CCC

b).Regression.









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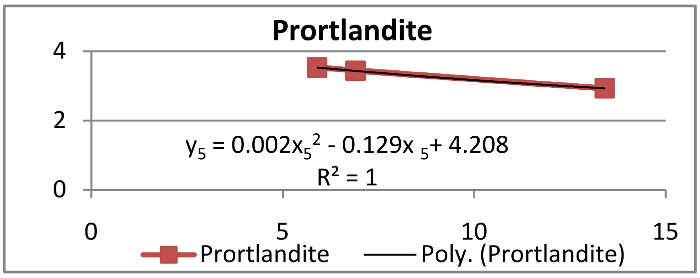


Predictive Model For Split Tensile Strength: Similarly for Split Tensile Strength, the mathematical model was developed, which can be used to predict strength based on the chemical composition of the material. The details of Mechanical Properties are obtained from figure 3 and their Chemical compositions are obtained from XRD diffraction patterns. The Mathematical models developed is as below. Thus Overall Split Tensile Strength(y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression

y=y1+y2+y3+y4+y5

$y=\{49.69-0.0162x_1+0.005x_2-0.001x_2^2-2.403x_3+0.036x_3^2+0.027x_4-0.001x_4^2-0.05\log x_{5}\}$

y(Tensile Strength in Mpa) = {49.69-0.016(% of Alite)+0.005(% of Ettringite)-0.001(% of Ettringite)^2-2.403(% of Quartz)+0.036(% of Quartz)^2+0.027(% of Calcite)-0.001(% of Calcite)^2-0.05log(% of Portlandite)}

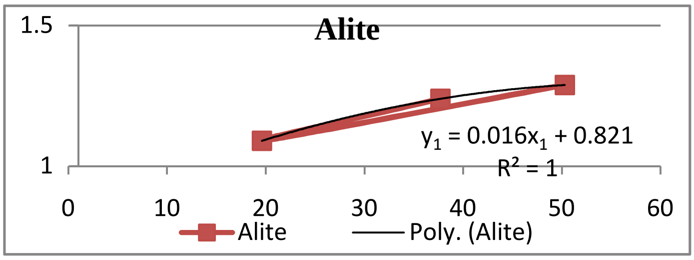
C. Predictive Model for Flexural Strength: Similarly for Flexural Strength, the mathematical model was developed, which can be used to predict strength based on the chemical composition of the material. The details of Mechanical Properties are obtained from figure 3 and their Chemical composition details from XRD diffraction patterns. The Mathematical models developed is as below,

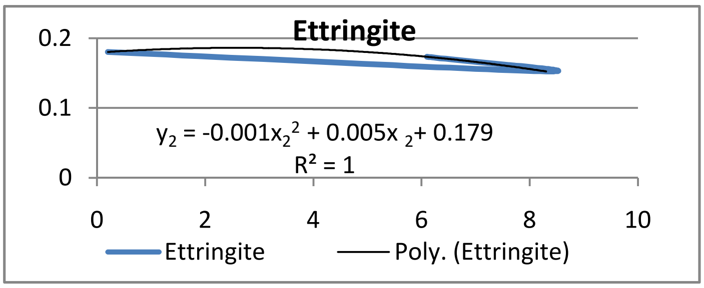
Figure.8 Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Split Tensile Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

a). Chemical Composition and Split Tensile strength of different types of concrete

Type of Concrete	Split Tensile Strength (Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
CC	3.54	37.7	6.1	45.7	3.6	6.9
RAC	3.112	19.6	8.3	45.2	13.5	13.4
TRAC	3.68	50.3	0.2	33.2	5.1	5.9

b).Regression





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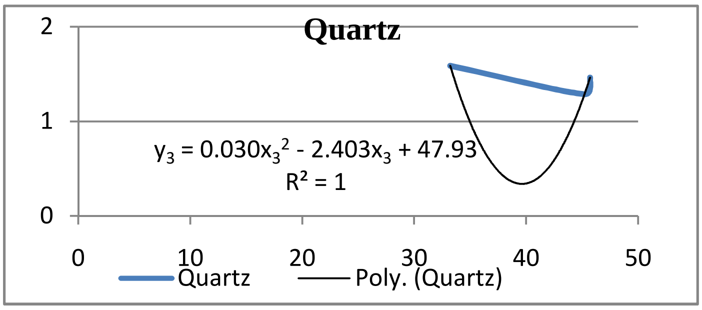
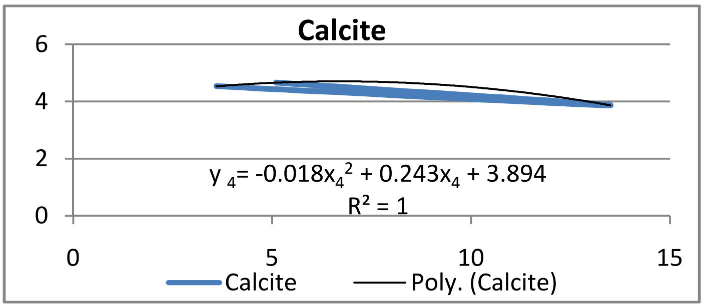




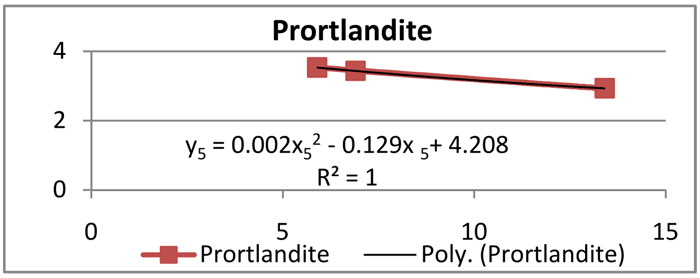
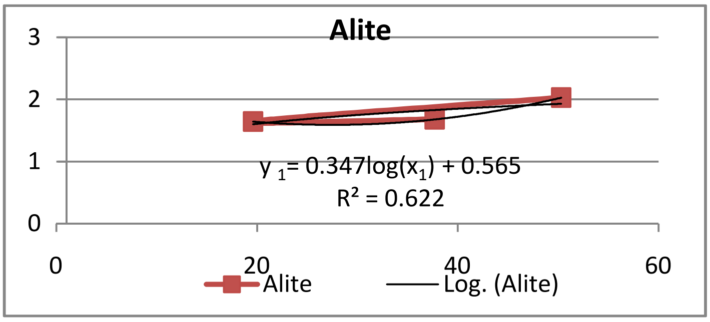


Figure. 9 Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Flexural Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

a).Chemical Composition and Flexural strength of different types of concrete.

Type of Concrete	Flexural Strength (Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portla (%)
(CC)	4.8	37.7	6.1	45.7	3.6	6.9
(RAC)	4.7	19.6	8.3	45.2	13.5	13.4
(TRAC)	5.8	50.3	0.2	33.2	5.1	5.9

b).Regression



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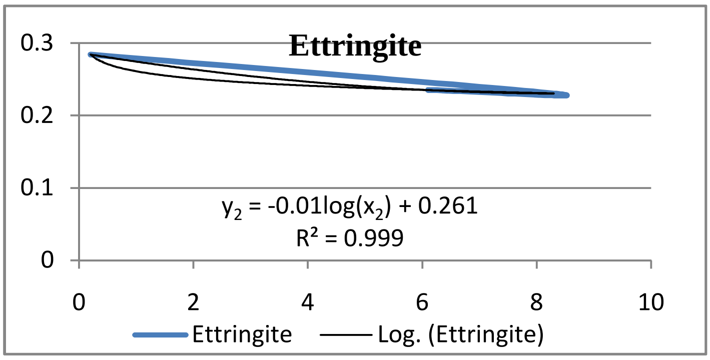
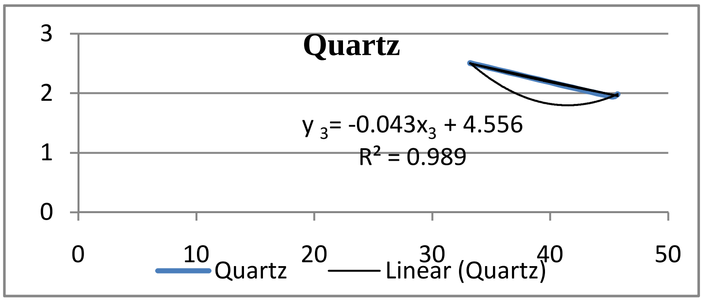
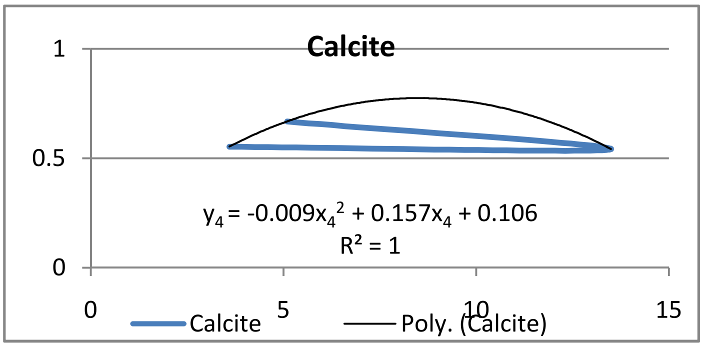
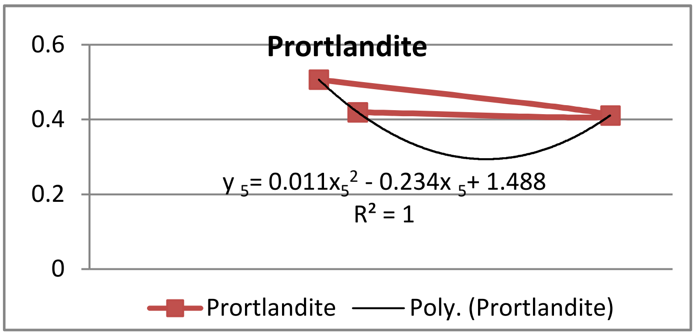








Thus Overall Flexural Strength(y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

$$y=y1+y2+y3+y4+y5$$

$$y= \{6.976+0.0347\log x_1-0.01\log x_2-0.043x_3+0.157x_4-0.009x_4^2-0.234x_5+0.011x_5^2\}$$

y (Flexural Strength in Mpa) = {6.976+0.347log (% of Alite)-0.01log(% of Ettringite)-0.043(% of Quartz)+0.157(% of Calcite)-0.009(% of Calcite)^2-0.234(% of Portlandite)+0.011(% of Portlandite)^2}

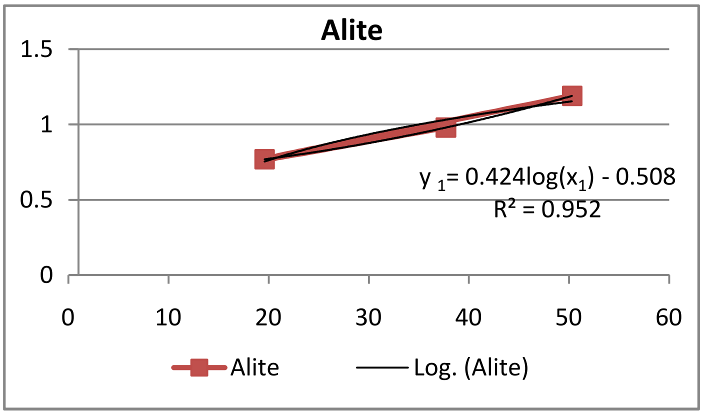
Predictive Model for Shear Strength:-Similarly for Shear Strength, the mathematical model was developed, which can be used to predict strength based on the chemical composition of the material. The details of Mechanical Properties are obtained from figure.3 and their Chemical composition details from XRD diffraction patterns. The Mathematical models developed is as below,

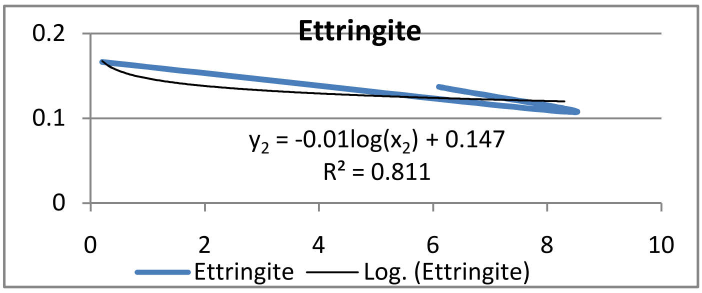
Figure 10. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Shear Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

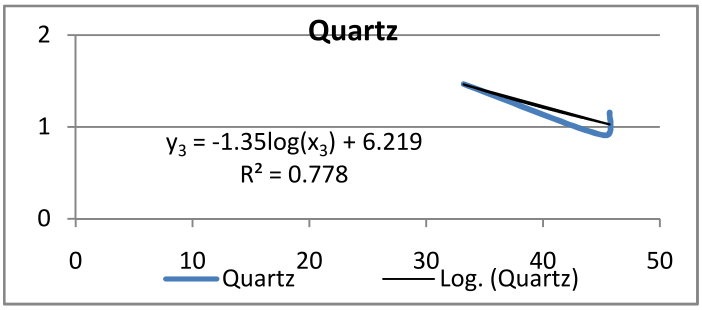
a). Chemical Composition and Shear strength of different types of concrete

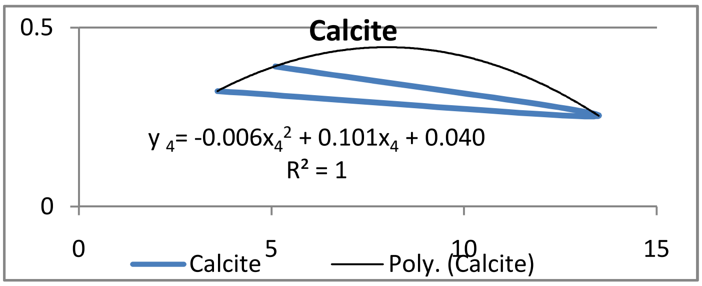
Type of Concrete	Shear Strength (Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
(CC)	2.8	37.7	6.1	45.7	3.6	6.9
(RAC)	2.2	19.6	8.3	45.2	13.5	13.4
(TRAC)	3.4	50.3	0.2	33.2	5.1	5.9

b).Regression









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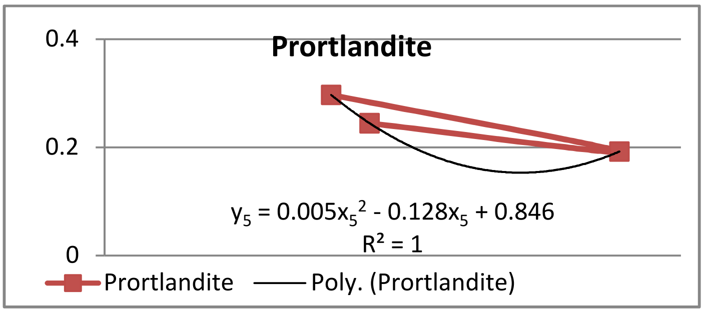


Thus Overall Shear (y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5

$y= \{8.344+0.424\log x_1-0.01\log x_2-1.35x_3+0.101x_4-0.006x_4^2-0.128x_5+0.005x_5^2\}$

y(Shear Strength in Mpa) = {8.344+0.424log(% of Alite)-0.01log(% of Ettringite)-1.35(% of Quartz)-0.091(% of Calcite)+0.004(% of Calcite)^2-0.128(% of Portlandite)+0.005(% of Portlandite)^2}

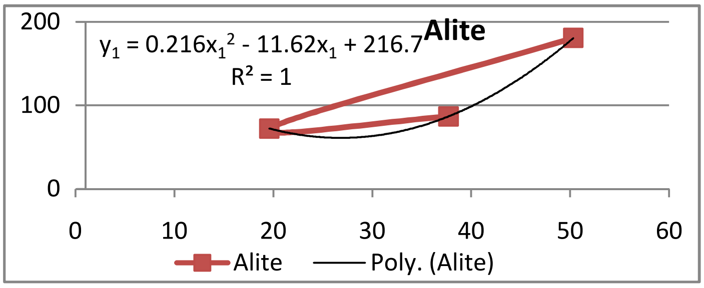
Predictive Model for Impact Strength:-Similarly for Impact Strength, the mathematical model was developed, which can be used to predict strength based on the chemical composition of the material. The details of Mechanical Properties are obtained from Figure.3 and their Chemical composition from XRD diffraction patterns. The Mathematical models developed is as below,

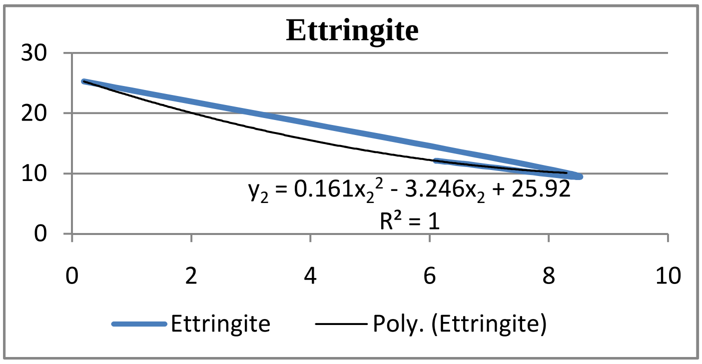
Figure 11. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Impact Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

a) Chemical Composition and Impact strength of different types of concrete.

Type of Concrete	Impact Strength (Knmm)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
(CC)	247.67	37.7	6.1	45.7	3.6	6.9
(RAC)	206.39	19.6	8.3	45.2	13.5	13.4
(TRAC)	515.98	50.3	0.2	33.2	5.1	5.9

b).Regression





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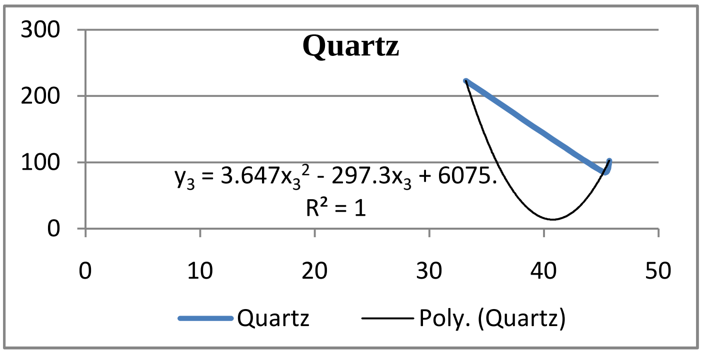
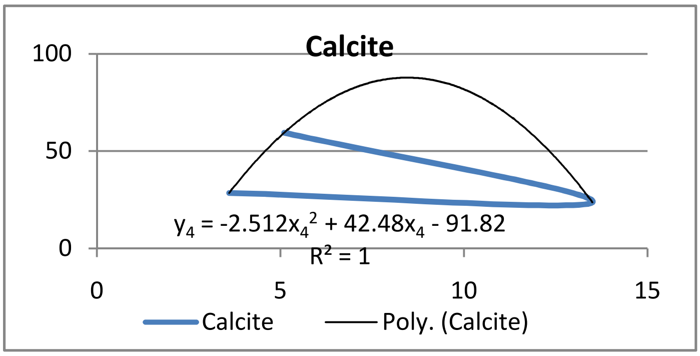
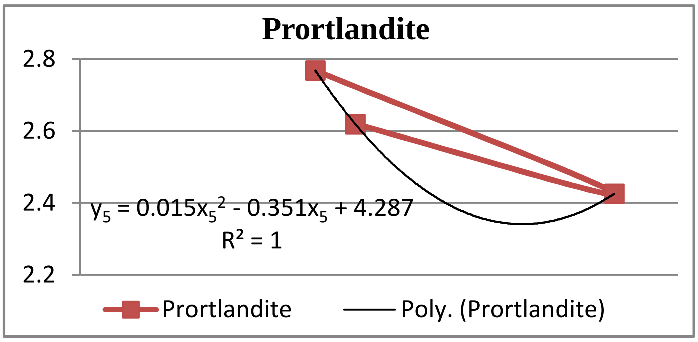






Thus Overall Impact Strength (y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5

$y= \{6246.08- 11.62x_1 + 0.216x_1^2 - 3.246x_2 + 0.161x_2^2 - 297.3x_3 + 3.67x_3^2 + 42.48x_4 – 2.512x_4^2 -0.234x_5 + 0.011x_5^2\}$

y(Impact Strength in Knmm) = {6246.08-11.62(% of Alite)+0.216(% of Alite)^2-3.246(% of Ettringite)+0.161(% of Ettringite)^2-297.3(% of Quartz)+3.67(% of Quartz)^2 +42.48(% of Calcite)-2.512(% of Calcite)^2-0.234(% of Portlandite)+0.011(% of Portlandite)^2}

Predictive Model for Modulus of Elasticity: Similarly for Modulus of Elasticity, the mathematical model was developed, which can be used to predict strength based on the chemical composition of the material.

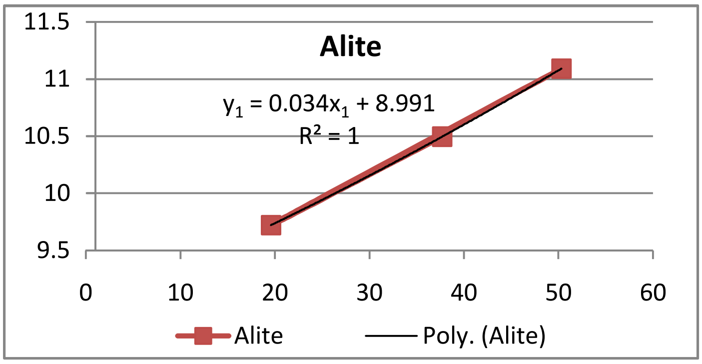
The details of Mechanical Properties are obtained from figure 4 and their Chemical composition from XRD diffraction patterns. The Mathematical models developed is as below,

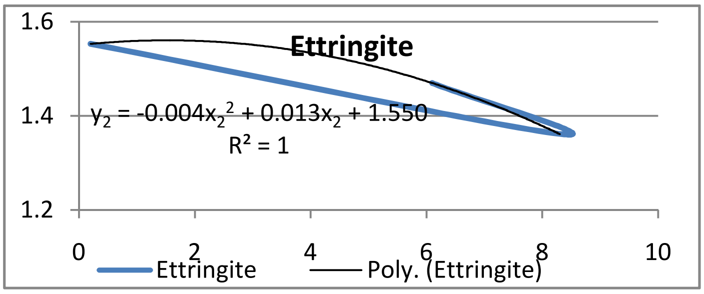
Figure 12. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Modulus of Elasticity and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

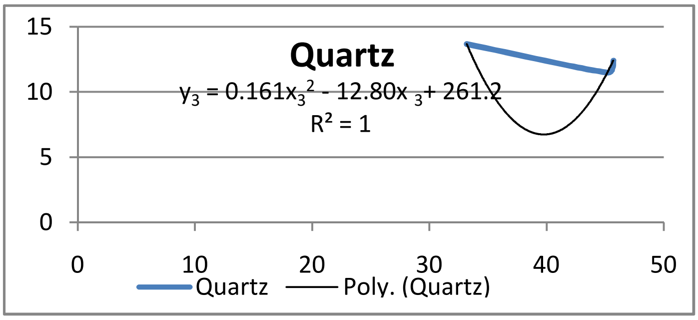
a) Chemical Composition and Modulus of Elasticity of different types of concrete

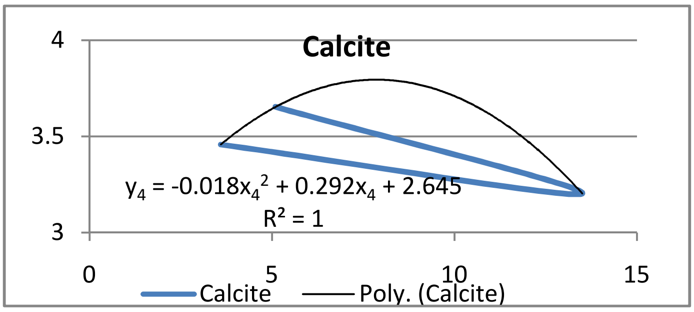
Type of Concrete	Modulus of elasticity (Gpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
(CC)	29.99	37.7	6.1	45.7	3.6	6.9
(RAC)	27.778	19.6	8.3	45.2	13.5	13.4
(TRAC)	31.69	50.3	0.2	33.2	5.1	5.9

b).Regression









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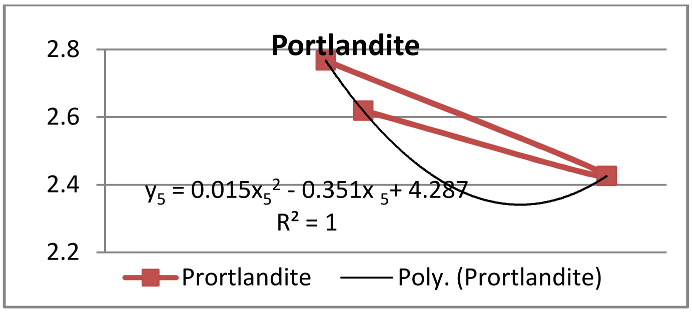


Thus Overall Impact Strength (y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5

$y= \{278.373+0.0342x_1 + 0.0136x_2 -0.004x_2^2 – 12.80x_3 + 0.161x_3^2 +0.292x_4 - 0.018x_4^2 -0.351x_5 + 0.015x_5^2 \}$

y(Modulus of Elasticity in Gpa) = {280+0.034(% of Alite)+0.013(% of Ettringite)-0.004(% of Ettringite)^2-12.80(% of Quartz)+0.161(% of Quartz)^2 +0.292(% of Calcite)-0.018(% of Calcite)^2-0.351(% of Portlandite)+0.015(% of Portlandite)^2}

Mathematical Model of Predicting Mechanical Properties of Cement Mortar from its Chemical Composition

Predictive Model for Compressive Strength: - The Curvilinear regression method is employed on data gathered from Mortar prepared with different types of the aggregates i.e. compressive strength and chemical composition details. The details of compressive strength are obtained from Figure 1 and Chemical composition details are obtained from XRD diffraction data. The detail step wise regression is as illustrated below.

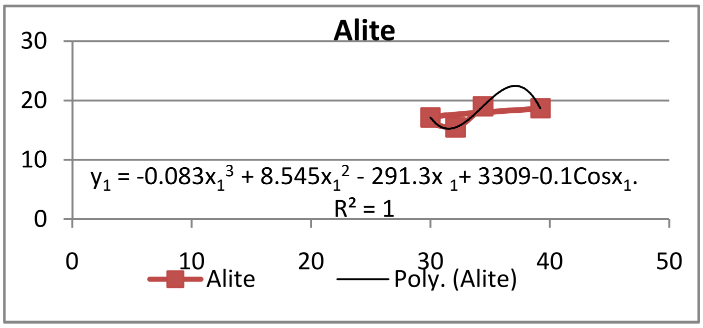
Figure 13. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Compressive Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

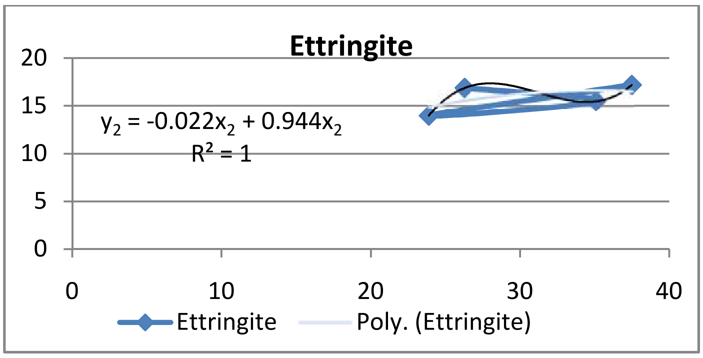
a). Chemical Composition and Compressive Strength of different types of concrete

Type of Mortar	CSCM (Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
(MFA)	55	39.2	26.3	29.9	1.9	2.6
(MMFA)	50.5	30	35.1	17	14	3.6
(MRFA)	45.5	32.1	23.9	7.9	18.5	15.7
(MTRFA)	56	34.4	37.5	17	0.5	2.4

Mortar prepared with Conventional aggregates(MFA), Mortar prepared with M-sand aggregates(MMFA), Mortar prepared with Untreated Recycled Fine aggregates(MRFA), Mortar prepared with Treated Recycled Fine aggregates(MTRFA).
Compressive Strength of Cement Mortar (Mpa)

b). Regression Process





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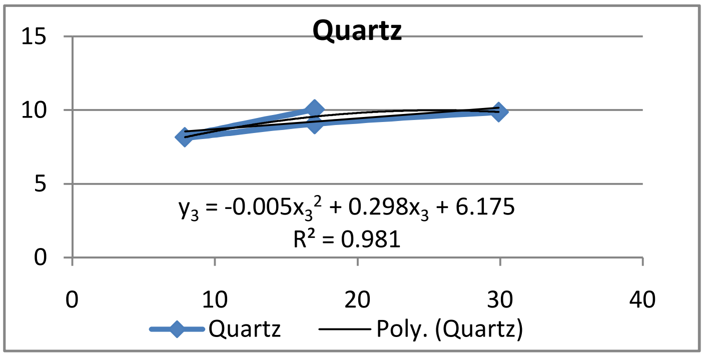
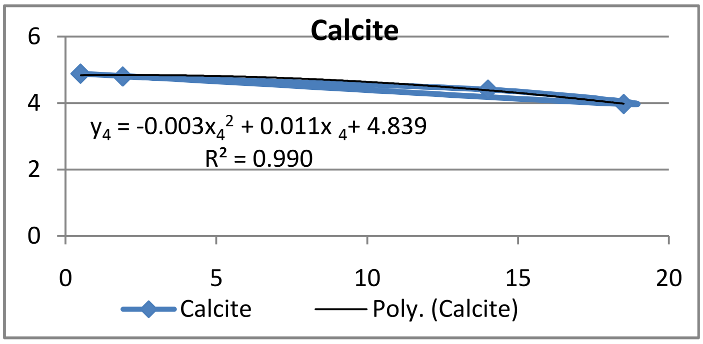
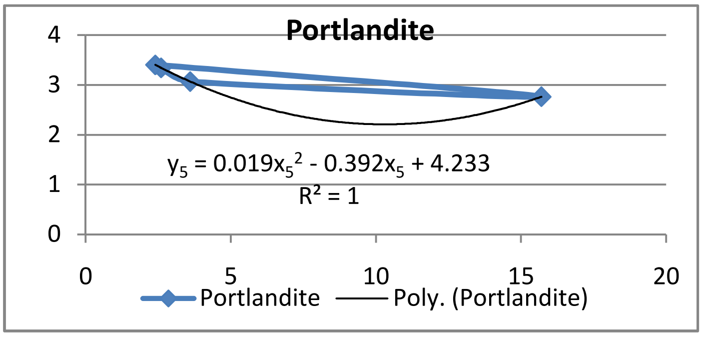






Thus Overall Compressive Strength(y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5

$y=\{3332.247-291.3x_1-0.1Cos(x_1)+8.545x_1^2-0.083x_1^3+0.944x_2-0.0224x_2^2+0.298x_3-0.005x_3^2+0.011x_4-0.003x_4^2-0.392x_5+0.019x_5^2\}$

y(Compressive Strength Mpa) = { 3332.247 -291.3(% of Alite) – 0.1(Cos(% of Alite))+ 8.545(% of Alite)^2 -0.083(% of Alite)^2+ 0.944(% of Ettringite) - 0.0224(% of Ettringite)^2 + 0.298(% of Quartz) -0.005((% of Quartz)^2 + 0.011(% of Calcite) - 0.003(% of Calcite)^2 - 0.392(% of Portlandite) + 0.019(% of Portlandite)^2 }

Mathematical Model of Predicting Mechanical Properties of concrete from Chemical Composition of aggregates

Predictive Model from Chemical Composition of Coarse Aggregates: - The Curvilinear regression method is employed on data gathered from untreated and treated coarse aggregates and the usage of it concrete.

The details of compressive strength are obtained from Figure 2 and Chemical composition details are obtained from XRD diffraction data. The detail step wise regression is as illustrated below.

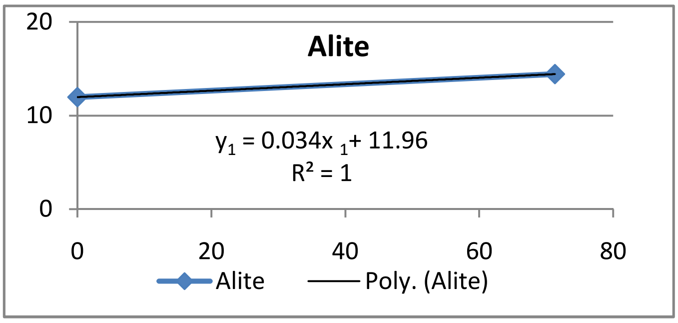
Figure.14 Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Compressive Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

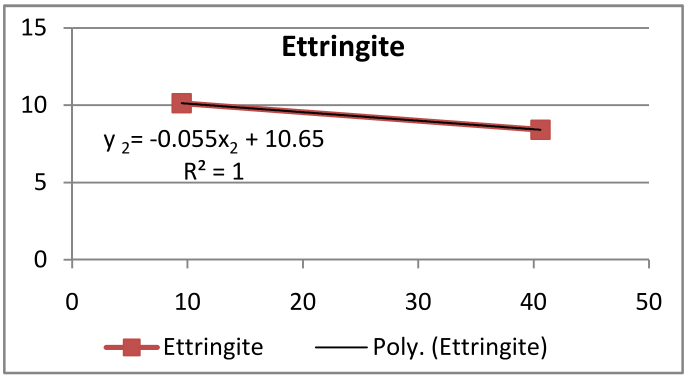
a). Chemical Composition and Compressive Strength of different types of concrete

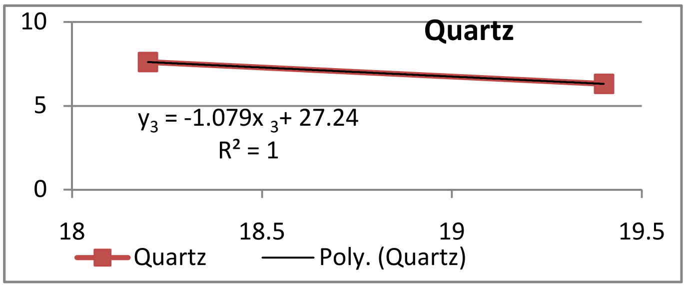
CSCM(Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
33.55	0	40.6	19.4	18.1	22
40.44	71.3	9.5	18.2	0	1

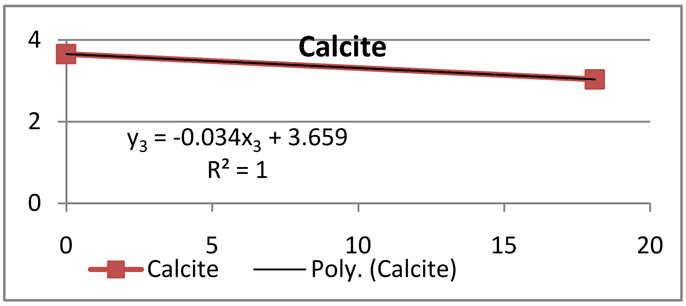
Compressive Strength of Cement Mortar Cubes at 28-days(Mpa)-CSCM

b). Regression Process









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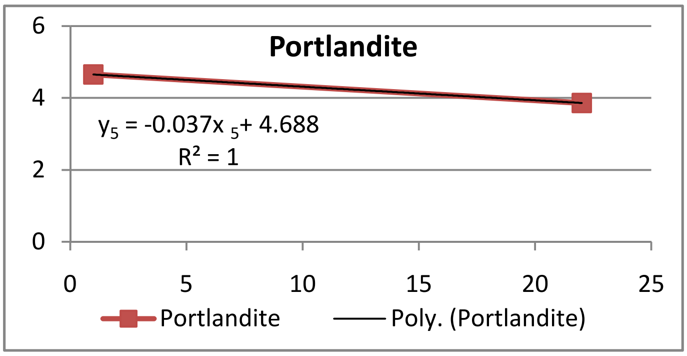


Thus Overall Compressive Strength(y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5

y= {58.197+ 0.034x_1-0.055x_2-1.079x_3-0.034x_4-0.037x_5}

y(Compressive Strength Mpa) = { 58.197+0.034(% of Alite) – 0.055(% of Ettringite) -1.079 (% of Quartz) -0.034(% of Calcite) – 0.037(% of Portlandite) }

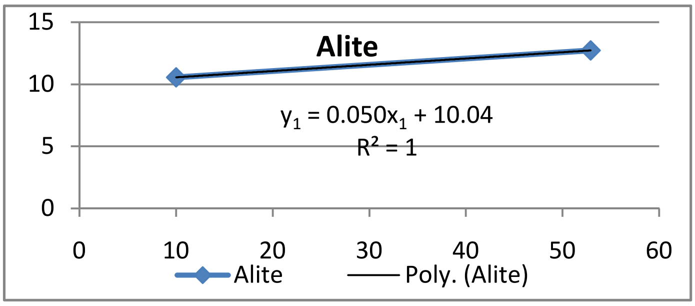
Predictive Model from Chemical Composition of Fine Aggregates: The Curvilinear regression method is employed on data gathered from untreated and treated Fine aggregates and the usage of it concrete. The details of compressive strength are obtained from figure 2 and Chemical composition details are obtained from XRD diffraction data. The detail step wise regression is as illustrated below.

Figure 15. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Compressive Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

a).Chemical Composition and Compressive Strength of different types of concrete

Compressive Strength of Cement Mortar Cubes at 28-days(Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
33.55	10	0	48.3	19.3	22.4
40.44	52.9	21.1	18.3	8.3	0.5

b). Regression Process



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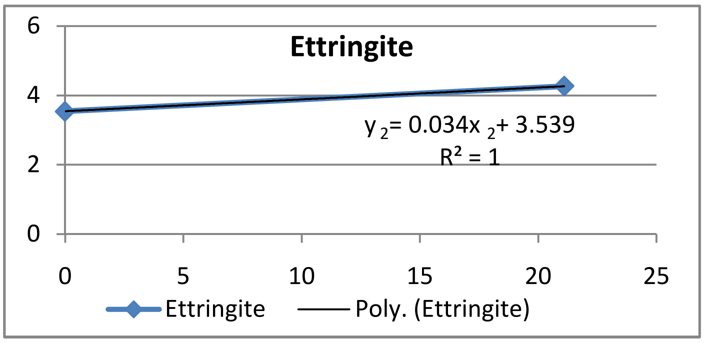
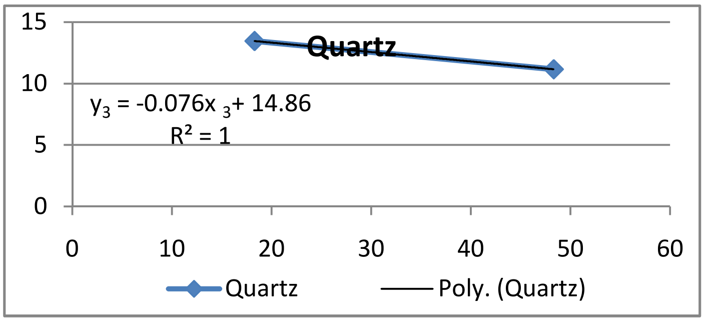
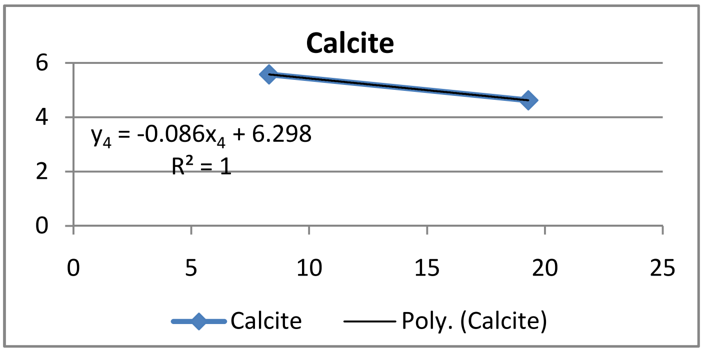
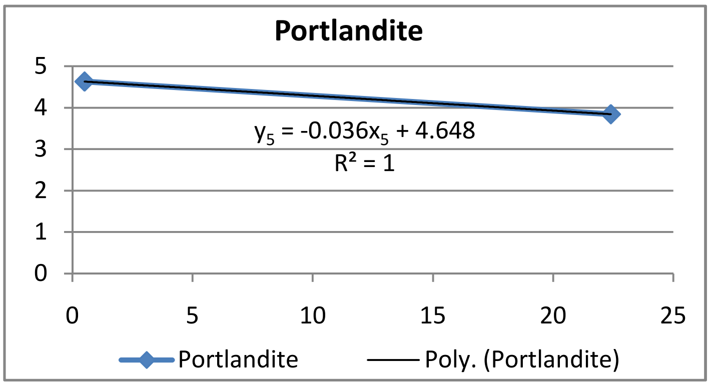








Thus Overall Compressive Strength(y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

y=y1+y2+y3+y4+y5
$y=\{58.197+ 0.034x_1-0.055x_2-1.079x_3-0.034x_4-0.037x_5\}$

y(Compressive Strength Mpa) = { 58.197+0.034(% of Alite) – 0.055(% of Ettringite) -1.079 (% of Quartz) -0.034(% of Calcite) – 0.037(% of Portlandite) }

Mathematical Model of Predicting Mechanical Properties of Cement Mortar from Chemical Composition of aggregates

Predictive Model from Chemical Composition of Fine Aggregates: - The Curvilinear regression method is employed on data gathered from fine aggregates used in the preparation of Cement Mortar. The details of compressive strength are obtained from Figure 1 and Chemical composition details are obtained from XRD diffraction data. The detail step wise regression is as illustrated below.

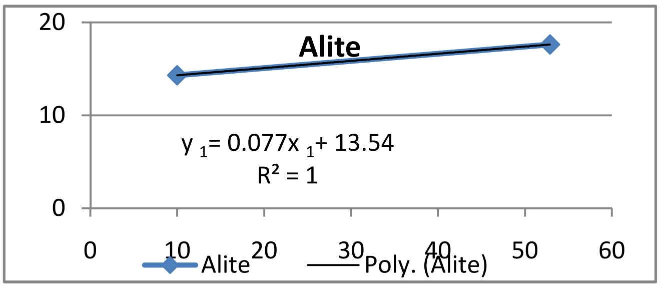
Figure 16. Step-Wise Curvilinear Regression Process on Predicting the Relationship between the Compressive Strength and the Chemical Composition of the Concrete Sample Prepared with Different Type of aggregates

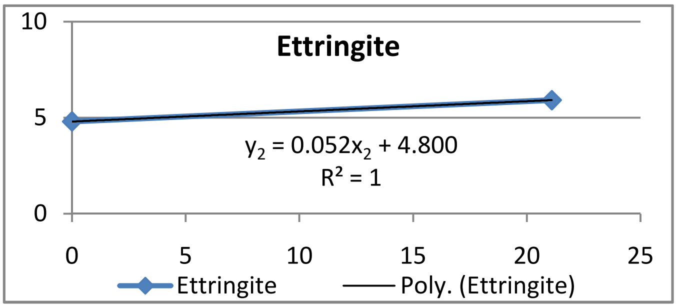
a).Chemical Composition and Compressive Strength of different types of concrete

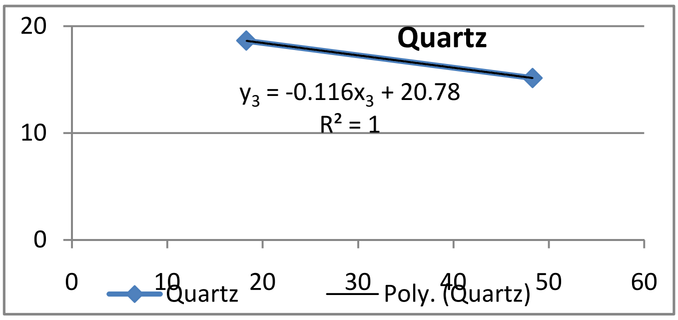
CSCM(Mpa)	Alite (%)	Ettringite (%)	Quartz (%)	Calcite (%)	Portlandite (%)
45.5	10	0	48.3	19.3	22.4
56	52.9	21.1	18.3	8.3	0.5

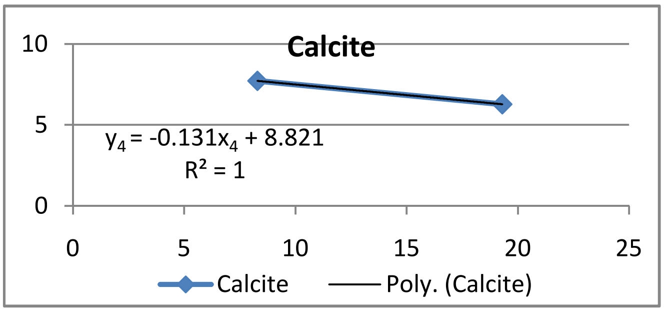
Compressive Strength of Cement Mortar Cubes at 28-days(Mpa)-CSCM

b). Regression Process









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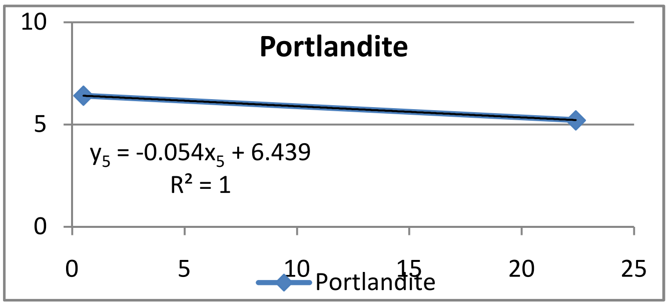

Thus Overall Compressive Strength(y) based on the Chemical Composition of Alite, Ettringite, Quartz, Calcite and Portlandite from Curvilinear regression is as below,

$$y=y1+y2+y3+y4+y5$$

$$y= \{54.38+ 0.077x_1+0.052x_2-0.116x_3-0.131x_4-0.054x_5\}$$

y (Compressive Strength Mpa) = {54.38+0.077(% of Alite+0.052(% of Ettringite) -0.116(% of Quartz) -0.131(% of Calcite) – 0.054(% of Portlandite) }

NOTES

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CONCLUSION

- The mathematical model developed helps in predicting the mechanical properties of the concrete/mortar mass by knowing the chemical constituents of the mass understudy with a probability factor of 0.95.
- The strength and performance of the concrete and mortar mass made of recycled demolished concrete aggregates can be assessed to precision by knowing the chemical constituents of the recycled aggregates used. These helps in assessing the quality of the recycled aggregates proposed to be used.
- The usage of treated recycled demolished concrete coarse and fine aggregates yielded more formation of calcium silicate and this resulted in improved mechanical properties of the concrete/mortar mass prepared with these aggregates. Thus, it infers the significance of the active role played by the treated recycled aggregates as compared to that of the inert role played by the conventional aggregates. In the mathematical model the positive value of the calcium silicate and its related compounds indicates the same.
- The developed mathematical model along with help of the hand held mineral detectors can be used as a tool in predicting the performance of the old concrete structures in a non-destructive way at a site within the fractions of minutes.

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