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Comparative Study on Various Modified Epoxy for Fiber Reinforced Polymer Strengthening Concrete Structure

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Abstract: Epoxy has been used as adhesive in Fiber Reinforced Polymer (FRP) strengthening systems for upgrading concrete structures all over the world. The most common type of epoxy is cold-cured epoxy resin which hardens and achieves considerable mechanical properties at ambient temperature. However, uncertainty occurs when it is applied to structures whereby the durability of the material will be an issue, therefore, modifications of epoxy are required to toughen the epoxy to suit the purpose of repairing a concrete structure. Hence, this research involves an investigation and comparison of various materials replacement such as quarry dust, rice husk ash (RHA), as well as waste glass powder to modify epoxy resin in terms of compressive and bond strength. By comparing the results collected from the previous study, the optimum value of materials replacement used in the samples which could improve compressive and bond strength would be found. The comparison and analysis were done by using basic statistical analysis which is mean, standard deviation, correlation, and regression. All of these statistical analyses were calculated and the results were generated in Microsoft Excel. Based on the analysis, it could be concluded that RHA consists of the highest value of compressive strength recorded which is 59.3MPa with 5% of RHA content in a sample. As for the bond strength investigated, quarry dust record the highest value of bond strength which is 3.565MPa with 15% of quarry dust content in a sample.

Keywords: Fiber Reinforced Polymer (FPR), Epoxy Resin, Modified Epoxy Resin, Quarry Dust, Rice Husk Ash (RHA),

1. Introduction

Throughout the years, it is well known that epoxy resin has a variety of applications whether in construction industries, electronics or electrical components, metal coatings, machinery, aerospace, and others due to its advantages which are low cost, have an outstanding bonding performance, exceptional mechanical properties, easy to handle, dimensional stability as well as has good resistance in the thermal

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and chemical reaction. (Kadhmi et al., 2018, Yang et al., 2018 & Sun et al., 2019). In addition to that, epoxy was invented by Dr. Pierre Castan and Dr. Sylvan Greenlee in the 1930s. The process of epoxy invention was by cross-linking the epoxy with hardener or reacting the epoxy itself through catalytic homopolymerization. Not to mention, there are several common substances used for hardeners which are polyamines, aminoamides, and phenolic compounds. The hardened reaction between epoxy resin and hardener is called curing (Epoxy Tomorrow's Technology Today, 2015). However, the original epoxy resin without any materials replacement or other substances added would have another issue such as brittle, thus adding or replacing part of epoxy resin substances it could improve the compressive and bond strength of the modified epoxy resin. The aim for this study are to investigate and compare the various materials replacement used to modify epoxy in term of compressive and bond strength as well as to identify the optimum value of each material replacement used which can improve the compressive and bond strength by using basic statistical analysis. Therefore, this study was done by collecting other researches or studies and comparing the results using basic statistical analysis such as mean, standard deviation, correlation, and regression.

2. Literature Review

This research focus on comparative study on various modified epoxy for Fiber Reinforced Polymer (FRP) strengthening of concrete structure. By comparing various type of modified epoxy resin properties such as compressive strength, bond strength, tensile strength, curing time of the modified epoxy and others, the most suitable materials added into the epoxy resin can be determined.

2.1 Epoxy Resin

Epoxy can be defined as a thermosetting polymer that has some good properties of chemical and mechanical. In addition to that, it also carries a few outstanding characteristics which are good insulation, excellent environmental and chemical resistance over a variety of temperature fluctuations (Tewari et al., 2012 & Saba et al., 2016 & Ibraheem and Bandyopaddhyay, 2017). Moreover, the main material in epoxy production is petroleum, however, petroleum is a non-renewable source thus petroleum is always in demand (Firdaus, 2016). The epoxy resin has two components that need to be mixed in the curing process which are resin and hardener. These two substances need to be mixed in a ratio that was recommended by the manufacturer (Abdullah et al., 2020).

Furthermore, there are 2 types of hardener commonly used namely Diamion Diphenyl Methane (DDM) and Treiethylene Tetramine (TETA). When both of these hardeners are mixed with epoxy, they will be known as Diglycidyl Ether of Bisphenol-A. Other than that, two common properties that need to be investigated for epoxy resin which is mechanical and chemical properties. Mechanical properties include compressive strength, flexural strength, and others (Agarwal & Agarwal, 2019). On the other hand, chemical properties that could be investigated are the curing and glass transition temperature, Tg as it involves chemical reaction for that particular substance (Fiore & Valenza, 2013). Additionally, the curing process could be done at room temperature if the viscosity of the epoxy resin is low and it will give good mechanical properties and excellent resistance against harsh environments (Frigione & Lettieri, 2018).

2.2 Rice Husk Ash (RHA)

Rice Husk is the agricultural residue or waste which record 20% of 649.7 million tons of rice produced annually worldwide (Food and Agriculture Organization of the United Nations, 2008). By considering the waste recorded, it can be said that the residue of rice husk needs to be managed and disposed of properly to avoid the waste abundance around the world. . Furthermore, the burning process for RHA need to be under controlled temperature which is below 800ºC to produce the ash consists of silica mainly in amorphous form. As there are few studies of using RHA as a material replacement in cement investigation but it is still an unknown field for the usage in modified epoxy resin (Habeed & Mahmud, 2010).

2.3 Quarry Dust

Quarry dust is also known as the residue from quarry mining with commonly in the size range of 0 - 4.75mm. Most of the quarry dust was obtained as a byproduct of the crushed igneous rock, sedimentary or gravel. Other than that, quarry dust is cheap and produced about 68 million tonnes annually (Das & Gattu, 2018). These quarry dust would be disposed into the landfill which would affect the environment and human health in the surrounding area. Therefore, by reusing the waste produced by quarry mining for other purposes, it could reduce the risk to human health due to the excessive quarry dust exposed and decrease the waste produced as well as the cost for waste disposal (Rosli, 2020).

2.4 Waste Glass Powder

Glass is being generated about million tons all over the world, thus producing a lot of wastes in return. As for its disposal, it would take a lot of energy, time as well as money. The common way of glass disposal is by disposing of it as a landfill. On the other hand, glass is mainly composed of silica which is unsustainable material. Thus, it cannot be decomposed naturally in the environment (Islam et al., 2016). As the disposal process would be costly, the glass waste could be reused for another purpose which is in this study as additive materials in epoxy resin which would be used to investigate the bond strength generated in each sample. The glass waste needs to be processed into a powder to ease the workability of mixing it into epoxy resin.

3. Methodology

The methodology of the comparative study of various modified epoxy resin for FRP strengthening concrete structure was done by collecting all of the data from previous studies such as quarry dust, RHA, and waste glass powder, either as a material replacement or additive material. The data collected were analyzed by using basic statistical analysis such as mean, standard deviation, correlation as well as regression using Microsoft Excel.

3.1 Experimental Set-Up

This study focuses on compressive and bond strength investigation. Based on the previous study collected compressive strength test was conducted on 3 sets of samples which involved 2 sets of samples of quarry dust and 1 set of samples of RHA. As for the bond strength test, it was conducted on 3 sets of samples which involved quarry dust, RHA, and waste glass powder. Tables 1 and 2 show the experimental set-up for compressive strength and bond strength, respectively.

Table 1 : Experimental Set-Up in Compressive Strength Investigation

Materials / Criteria	**Quarry Dust (Set A) (Rosli, 2020)**	**Quarry Dust (Set B) (Rosli, 2020)**	**RHA (Ruhen, 2020)**
Standard	BS 1881 - 116 : 1993	BS 1881 - 116 : 1993	ASTM C109
Content of materials replacement	10% - 40% of epoxy replacement	10% - 40% of resin replacement	5% - 20% of resin replacement
Size particle	600µm	600µm	300µm - 75µm
Ratio resin/hardener	2:1	2:1	2:1
Sample size	50mm x 50mm x 50mm / Cube	50mm x 50mm x 50mm / Cube	50mm x 50mm x 50mm / Cube
Curing days	7 days	7 days	7 days

Table 2 : Experimental Set-Up in Bond Strength Investigation

Materials / Criteria	**Quarry Dust (Zawawi, 2020)**	**RHA (Ruhen, 2020)**	**Waste Glass Powder (Chowaniec & Ostrowski, 2018)**
Standard	ASTM D4541	ASTM D4541	ASTM D4541
Content of materials replacement/additive material.	5% - 25% of epoxy replacement	10% - 40% of resin replacement	7.4% - 44.4% of added materials
Size particle	600µm	300µm - 75µm.	600µm
Ratio resin/hardener	2:1	2:1	2:1
Sample size	500mm x 500mm x 100mm / Slab	50mm x 50mm x 50mm / Cube	200mm x 200mm x 50mm / Slab
Curing days	7 days	7 days	7 days

3.2 Statistical Analysis

Several equations were used in this study such as mean, standard deviation, correlation, and regression as presented in Table 3. These statistical analyses were used to analyse the data collected from the previous study in the compressive strength and bond strength investigation. Mean was used to reduce the probability of error in an experiment as there are repetitive data collected to calculate the mean. By ensuring the value of the mean calculated is close to the data recorded, it is possible that the experiment doesn't have errors or have minor errors. Other than that, the values of standard deviation would be used to determine the reliability of data as the smaller the value of standard deviation, the more reliable the data recorded. Correlation and regression were used to determine the relationship between the variables used by stating whether the relationship is strong or weak and positive or negative. These relationships were determined by using the values of the coefficient of correlation. In addition to that, a coefficient of determination would be used to determine the best model used for each of the sets of data. The better model used would generate better results of the relationship between the variables used.

Table 3 : Statistical Analysis Equations

Statistical Analysis	Mean	Standard Deviation	Correlation	Regression
Equation	$\bar{x} = \frac{\sum x}{n}$	$s = \sqrt{\sum[(X_i - \bar{x})^2/n - 1]}$	$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{(n-1)s_x s_y}$	$Y' = a + bX$

Symbol's meaning	x : each value recorded for both compressive and bond strength n : number of data collected	Xi : each value recorded for both compressive and bond strength $\bar{x}$: calculated mean for data collected n : number of data collected	X : Independent variable Y : Dependent variable n : Number of observation $\bar{X}$, $\bar{Y}$: Mean of the independence and dependence variables s_X , s_Y : Standard deviation of the independence and dependence variables	Y' : predicted value of the response variable Y (dependent variable) X : predictor variable (independent variable) a : estimated value of Y when X = 0 (the Y-intercept) b : the slope of the regression line

4. Results and Discussion

This section shows the results and discussion for all of the data collected for quarry dust, RHA as well as waste glass powder for this study. Different materials used as a replacement or added in a sample give different results in compressive strength and bond strength recorded.

4.1 Compressive Strength Investigation

The compressive strength test was tested on 3 samples which involved quarry dust and RHA as materials replacement as shown in Table 4.. The table shows the calculated mean and standard deviation for each of the samples. The mean of the samples was calculated to reduce the possibilities of the error of the experiment conducted while the standard deviation was calculated to find the data reliability as the smaller the value of standard deviation calculated, the more reliable the data recorded.

Table 4 : Compressive Strength Test Results

Quarry Dust (Set A) (Rosli, 2020)			
Quarry Dust (%)	**Epoxy (Resin + Hardener) (%)**	**Mean (MPa)**	**Standard Deviation**
0	100	62.0	0.9849
10	90	47.0	1.2897
20	80	59.1	1.7000
30	70	42.7	1.5567
40	60	31.4	2.3335

Quarry Dust (Set B) (Rosli, 2020)			
Quarry Dust (%)	**Epoxy (Resin + Hardener) (%)**	**Mean (MPa)**	**Standard Deviation**
0	100+100	62.0	0.9849
10	90+100	46.4	1.1314
20	80+100	28.6	1.8230
30	70+100	30.4	0.9018
40	60+100	9.4	0.8185
RHA (Ruhen, 2020)			
RHA (%)	**Epoxy (Resin + Hardener) (%)**	**Mean (MPa)**	**Standard Deviation**
0	100+100	54.5	0.8021
5	95+100	59.3	0.6028
10	90+100	51.7	1.1930
15	85+100	46.3	1.1060
20	80+100	31.6	1.1719

Table 5 shows the comparison for the data collected in quarry dust sets A and B as well as RHA. The data shown were the highest value recorded for compressive strength and their respective materials replacement content used. The higher values mean that the objective of the experiments was achieved as it can sustain more compression force applied on the samples. The coefficient of correlation, r, and determination, R^2 explain the relationship between the variables as it would estimate the effect of the compressive strength based on the materials replacement content as presented in Figure 1. Meanwhile, significance F and P-values provide better model of graph used for each data sets.

Table 5: Comparison for Quarry Dust and RHA in terms of compressive strength

Compressive Strength Investigation	Quarry Dust		RHA
	A	**B**	
Highest Value of Mean	59.1MPa	45.6MPa	59.3MPa
Optimum Value of Material Replacement	20% of QD	10% of QD	5% of RHA
Coefficient of Correlation, r	-0.8294	-0.9523	-0.8743
Coefficient of Determination, R^2	0.6878	0.9069	0.7644
Adjusted R^2	0.5829	0.8759	0.6859
Standard Error	8.0592	6.9685	5.9732
Observation, n	5	5	5
Significance F	0.0824	0.0124	0.0525

P-value	0.0022 0.0824	0.0016 0.0124	0.0010 0.0525
Null Hypothesis, Ho	Rejected	Rejected	Rejected
Relationship	Strong negative relationship	Strong negative relationship	Strong negative relationship

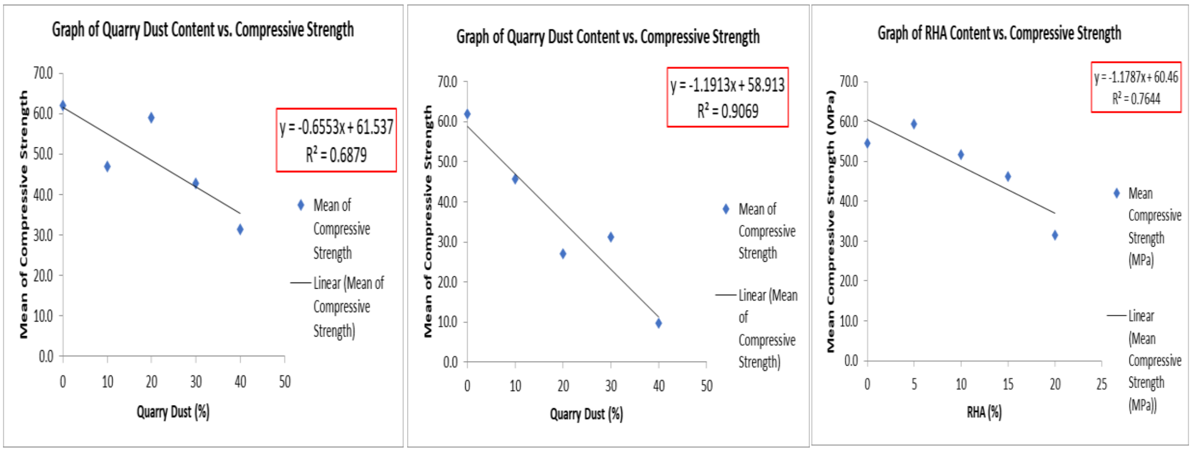

Figure 1 : Graphs for Quarry Dust Set A (left), Quarry Dust Set B (middle), and RHA (right)

In order to prove understanding on the statistical data provided in the Table 5 and Figure 1, one example of analysis can be explained in this section. An example of RHA, where 20% replacement gives the highest mean compressive strength of 59.3MPa. the coefficient of correlation,r of -0.8743 indicates, strong negative relationship which shows that when the value of RHA content increases, it will likely cause the compressive strength to decrease.. The coefficient of determination of RHA gives 0.7644 or 76.44% of the variance in the RHA content in samples can be accounted for the compressive strength measures.. The Significance F and P-values recorded also less than 0.1 which is a level of significance, means that the null hypothesis which is the addition of material replacement does not affect the compressive strength of the modified epoxy resin can be rejected.

4.2 Bond Strength Investigation

Table 6 shows the data collected from the previous experiment, mean and standard deviation calculated in their respective data. The highest mean recorded for quarry dust samples is 3.565MPa with 0.029 standard deviations for 15% quarry dust content. The standard deviation calculated for this set of data was the lowest, thus showing that the data recorded are more reliable than the other samples for quarry dust. As for RHA samples, the highest value of bond strength recorded is 3.307MPa with 0.006 standard deviations for 5% RHA content while waste glass powder shows 24.2% of material content has the highest value of bond strength recorded which is 3.067 but has a high value of standard deviation which is 0.305. This value shows that the data recorded is less reliable compared to the sample 7.4% of material content that has 0.081 standard deviations, even though the bond strength recorded for this sample is only 2.313MPa.

Table 6 : Bond Strength Test Results

Quarry Dust (Zawawi, 2020)			
Quarry Dust (%)	**Epoxy (Resin + Hardener) (%)**	**Mean (MPa)**	**Standard Deviation**
0	100	2.425	0.194
5	95	2.519	0.106
10	90	3.005	0.346
15	85	3.565	0.029
20	80	2.920	0.152
25	75	2.759	0.160
RHA (Ruhen, 2020)			
RHA (%)	**Epoxy (Resin + Hardener) (%)**	**Mean (MPa)**	**Standard Deviation**
0	100	3.423	0.060
5	95	3.307	0.006
10	90	3.107	0.031
15	85	2.463	0.106
20	80	2.187	0.080

Table 6 : Bond Strength Test Results (continued)

Waste Glass Powder (Chowaniec & Ostrowski, 2018)			
Waste Glass Powder (%)	**Epoxy (Resin + Hardener) (%)**	**Mean (MPa)**	**Standard Deviation**
0	100	2.707	0.120
7.4	100	2.313	0.081
13.8	100	2.433	0.159
19.4	100	1.777	0.121
24.2	100	3.067	0.305
28.6	100	2.787	0.087
32.4	100	2.200	0.092
35.9	100	2.533	0.405
39.0	100	2.440	0.557
41.9	100	2.607	0.292
44.4	100	2.123	0.250

Table 7 compares statistical data for quarry dust, RHA and Waste Glass. he results for the bond strength test shows that quarry dust contains the highest value which is 3.565MPa and the second-highest value shows is RHA which is 3.3.07MPa. The lowest value for the bond strength is for the waste glass powder sample which is 3.067MPa. On the other hand, bond strength investigation gives a different model for the graphs generated as it was chosen based on the value of the coefficient of determination, significance F, P-values. The highest value of the coefficient of determination among the model which is linear, quadratic as well as cubic generally would be the best model, and the lowest value of significance F and P-values would be the best model chosen. Therefore, the best model chosen for the quarry dust sample is quadratic regression, linear regression for RHA, and cubic regression for waste glass powder.

Even though quarry dust gives the highest value of bond strength, RHA has the least value of significance F and P-values. These results show that the variable y which is bond strength recorded is more dependent on the variable x which is the material replacement or additive material content for RHA compared to the quarry dust and waste glass powder. The coefficient of determination for RHA is also the highest compared to the other 2 sets of samples which are quarry dust and waste glass powder. The coefficient of determination for RHA samples is 0.9311 or 93.11% which shows there is 93.11% of the variance in the RHA content in the samples can be accounted for the bond strength measures.

Table 7: Comparison for Quarry Dust, RHA, and Waste Glass Powder in terms of bond strength

Bond Strength Investigation	Quarry Dust	RHA	Waste Glass Powder
Highest Value of Mean	3.565MPa	3.307MPa	3.067MPa
Optimum Value of Material Replacement	15% of QD	5% of QD	24.2% of RHA
Coefficient of Correlation, r	0.8241	-0.9649	-0.4372
Coefficient of Determination, R^2	0.6791	0.9311	0.1912
Adjusted R^2	0.4651	0.9081	-0.1555
Standard Error	0.2994	0.1647	0.3774
Observation, n	6	5	11
Significance F	0.1	0.0078	0.6631
P-value	0.0036 0.0947 0.1249	0.0001 0.0078	0.0001 0.2886 0.2555 0.2469
Null Hypothesis, Ho	Rejected	Rejected	Accepted
Relationship	Strong positive relationship	Strong negative relationship	Weak negative relationship

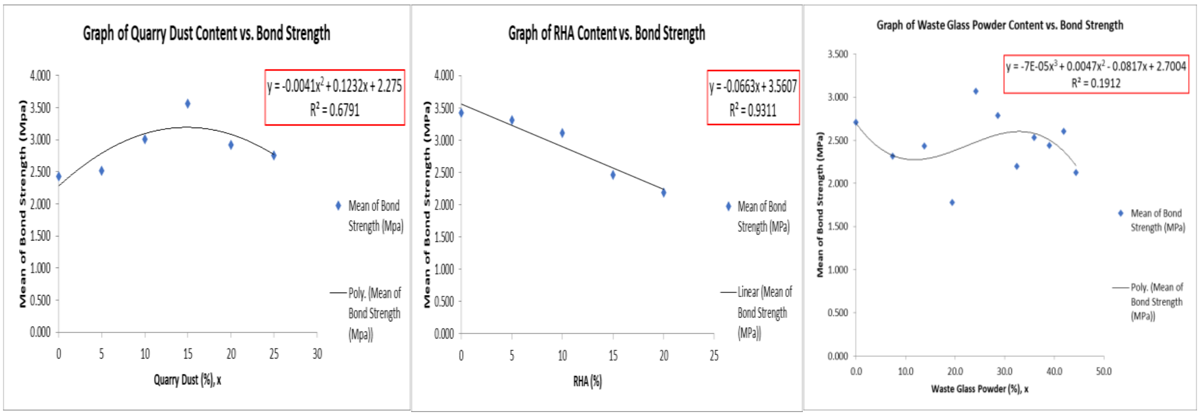

Figure 2 : Graphs for Quarry Dust (Left), RHA (Middle), and Waste Glass Powder (Right)

5. Conclusion

Based on the analytical results obtained in Microsoft Excel, it can be concluded that RHA gives the best results of all the samples for both of compressive strength and bond strength test. RHA produced the highest value for compressive strength which is 59.3MPa and the second-highest value for bond strength which is 3.307MPa. Both of these values were produced using 5% content of RHA in each sample. This means that 5% of RHA content is the optimum value for both compressive and bond strength investigation. The relationship between the variables in each of the investigations for RHA was also good which is a strong negative relationship. The strong relationship indicates that the variables of the results were related and a strong negative relationship means that if the RHA content increase it is likely caused the compressive and bond strength to be decreased.

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