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JAITA

http://publisher.uthm.edu.my/ojs/index.php/jaita

e-ISSN : 2716-7097

Journal of Advanced Industrial Technology and Application

X-Ray Fluorescence, Strength Testing and 3D-Analysis of Steel Fibre Reinforced Concrete Specimen

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DOI: https://doi.org/10.30880/jaita.2022.03.02.004
Received 24 Sebtember 2022; Accepted 24 November 2022; Available online 8 December 2022

Abstract: This experimental study investigated steel fiber reinforced concrete (SFRC) specimen's performance by using to X-Ray Fluorescence (XRF) test, Flexural Strength test, Compressive Strength test and Rebound Hammer test. The experimental result of the compressive strength test was further analyzed by 3D Analysis using Stat-Ease Design-Expert V13 to correlate the compressive strengths to the elemental composition of the concrete structure. The result showed that the amount of Calcium Oxide (CaO) in the sample was lower than the composition of Ordinary Portland Cement (OPC) used. Thirty-six (36) beam samples of 100mm x 100mm x 500mm size and twelve (12) cube samples of 100mm x 100mm x 100m size were prepared with different percentages of steel fiber (0.5%, 1.0% and 1.5%) to determine the optimum dosage. All samples were tested at 7, 14 and 28 days. It can be concluded that the analysis shows a low significant effect at an early aged concrete but showing a slightly increased in compression and flexural strength at a later age. The results also showed that the addition of steel fiber causes the reduction of slump value (workability). Recommended optimum percentage range of steel fiber addition in concrete is proposed. The relation among rebound hammer number, compressive strength and flexural strength of the specimens was also discussed.

Keywords: Steel fiber reinforced concrete, XRF, Flexural test, Compressive test, 3D-Analysis and rebound

1. Introduction

Concrete structures are one of the most common type of structures used around the world. A conventional reinforced concrete structure normally consists of concrete and steel reinforcement. It is a popular building material as it is strong, easy to work with, durable and affordable. Unconventionally, the addition of steel fiber in concrete is one of many attempts to improve its mechanical properties [1-5]. Additionally, several studies showed that for concrete mixtures in which the steel fibers are evenly scattered, significantly reduce cracks caused by variations in relative humidity and temperature [6-9]. A study also found that flexural strength of concrete is about 10-20% of compressive

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strength depending on type, size and volume of coarse aggregate used. It can be found direct measure by raising the compressive strength to the 2/3 power and multiplying that by 2.3 [10]. Compressive strength method is also correlated with the Rebound hammer method [11-13]. The experimental result of the compressive strength test can be further analyzed by 3D Analysis using Stat-Ease Design-Expert V13 to correlate the compressive strengths to the elemental composition (XRF) of the concrete structure. A study was also done by using Research Surface Methodology (RSM) to find the optimum workability water/cement ratio, slump and compressive strength [14].

Based on the literature study, it could be seen that various research focused on the utilisation of many types of fibres and also waste materials in producing a more sustainable and enhanced performance of concrete structures. The mechanical properties of the concrete structures may be improved by the incorporation of these materials. Therefore, it is vital to explore the optimum percentage of the steel fiber in concrete and its effect on the compressive strength, flexural strength, rebound hammer and XRF data as compared to the control specimen (conventional RC specimen). Hence, the focus of this study is to investigate the SFRC specimen performance by using compressive strength, flexural strength, rebound hammer and XRF tests. This study can also provide an insight into the applicability of the 3D analysis in producing SFRC specimen with optimum steel fiber percentage.

2. Methodology

Thirty-six (36) beam samples of 100mm x 100mm x 500mm size and twelve (12) cube samples of 100mm x 100mm x 100m size were prepared with 3 different percentages of steel fibre; 0.5%, 1.0% and 1.5% and Reinforced Concrete (RC) structure was used as control samples. The specification of the SFRC and RC samples were tabulated in Table 1. The samples were left in the curing tank and taken out at 7th, 14th and 28th days for testing purposes. The experimental testing done were Rebound Hammer (ASTM C 805-02 2002)[15], X-Ray Fluorescence (ASTM C150 OPC)[16], Flexural and Compression test. The concrete mix design targeted concrete strength of 60 N/mm^2 at 28 days. From the design mix, it was assumed that the proportion defective of 5% based on BS8110-1[17] and standard deviation of 8 N/mm^2 and the target mean strength 43 N/mm^2. The cement was OPC type. Crushed coarse aggregate 10mm and uncrushed fine aggregate were considered. The water-cement ratio 0.2 by specified slump flow 550-700 mm was 200 kg/m^3 and cement content was 1000 kg/m^3. Therefore, the total aggregates are 1233 kg/m^3 which combination of 433 kg/m^3 fine aggregate and 800 kg/m^3 coarse aggregate. Total steel fibre of the 0.5%, 1.0% and 1.5% batches used is 11.74 kg. For the control samples, main bar of Y8 and stirrup of R6 were taken into consideration. Table 2 summarizes detail of raw materials used in this study. Fig. 1 shows the first batch sample for 0.5% SFRC out of the 36 beams and 12 cubes sample. The casting starts by pouring cement into the heavy-duty mixer and blending it to break the clumped cement. Tap water, admixture, sand and coarse aggregates were added first and then steel fibre was added at last part. The mixing was constantly checked to ensure that the paste mix well until the bottom of the pan. The total duration of the mixing process for this study is within 15 - 20 minutes per mix. Next, a free flow test was carried out for fresh concrete paste for the first three mixes using a prepared slump cone and board. Time taken for the paste to reach 500mm and the diameter of the flowable concrete paste on the slump board were recorded. It was observed that the addition of steel fibre causes the reduction of slump value. The fresh concrete was poured into the prepared 100mm x 100mm x 500mm beam moulds and cube moulds then vibrated on the mechanical vibrating table for a few seconds. The processes were repeated for every mix and the equipment used was cleaned afterwards. The mould was dismantled after concrete hardened approximately 24 hours and the mould was cleaned by using proper tools. The samples were weighted, labelled and cured in the proper tank (ensure the sample was well soaked into the water). On the testing day, the samples were taken out from the curing tank and dried before its weight were recorded. The samples were tested at 7-day, 14-days and 28-days. Weighted samples were then carried out for NDT test, which were XRF (Fig. 2) and Rebound Hammer (Fig. 3) and followed with Compressive test and Flexural test (Fig. 4).

Table 1 - Concrete mix proportion

SFRC BATCH	Ordinary Portland Cement	Fine Aggregate	Coarse Aggregate	Water	Master Glenium ACE8538	Steel Fibre	Total weight	Unit
	1000.0	433.0	800.0	200.0	16.0		2449.0	kg/m^3
0.5%	49.5	21.43	39.60	9.90	0.79	1.96	123.18	kg
1.0%	49.5	2.43	39.60	9.90	0.79	3.91	125.14	kg
1.5%	49.5	21.43	39.60	9.90	0.79	5.87	127.09	kg
Control (RC)	49.5	21.43	39.60	9.90	0.79		121.23	kg

Table 2 - Detail of raw materials used

Material	Photos	Material	Photos
Ordinary Portland Cement, OPC - Tasek Cement		Coarse Aggregate - Passing 10mm	
Hyper Plasticizer Admixture - MasterGlenium ACE 8538		Steel Fibre - Flat Crimped 0.2mm thickness	
Fine Aggregate - Passing 6mm		Stirrup - 50mm x 50mm of R6	
Tap water - 0.2 water/cement ratio		Main bar - 450mm x 4side of Y8	

Fig. 1 - Samples Prepared

Fig. 2 - Portable XRF used to detect the element composition of the concrete surface

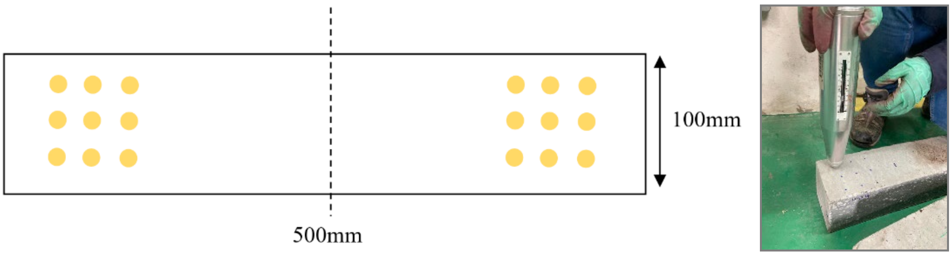


Fig. 3 - Test point of Rebound Hammer on the surface of the specimen

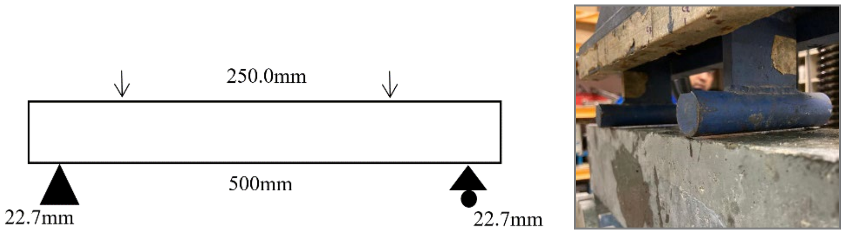


Fig. 4 - Four-Point Flexural Test Setup

3. Results and Discussions

The results from the experimental testing done were further discussed as follows;

3.1 Elemental Composition

Calcium Oxide, CaO or lime was the main components of cement in table 3. From the results shown, combination SO3 and MgO content exceeded the range levels of tabulated data from ASTM standard. Cement content and SiO2 and Fe2O3 content are slightly higher than the range levels. The main components of cement powder 58.6 - 66.3% shows a decrease in the sample's element for about 10.0% in Fig. 5 as it became paste after mixing with water, admixture and aggregate. The total elemental composition data percentage might exceed 100% indicated error in instruments [18].

Table 3 - Element composition in cement

Element Composition	ASTM C150 OPC Content %	0.5% SF	1.0% SF	1.5% SF	Control
Calcium Oxide, CaO	58.6 - 66.3	53.1191	51.7435	47.8801	52.6348
Silica, SiO2	18.7 - 22.0	31.0762	35.6878	36.8095	30.6543
Alumina, Al2O3	4.7 - 6.3	5.4256	4.7338	5.9242	4.8563
Iron Oxide, Fe2O3	1.6 - 4.4	5.5229	4.3815	4.5960	4.2576
Others: MgO, NaO, K2O, SO3	1.8 - 4.6	5.0443	4.4576	4.7264	5.3677

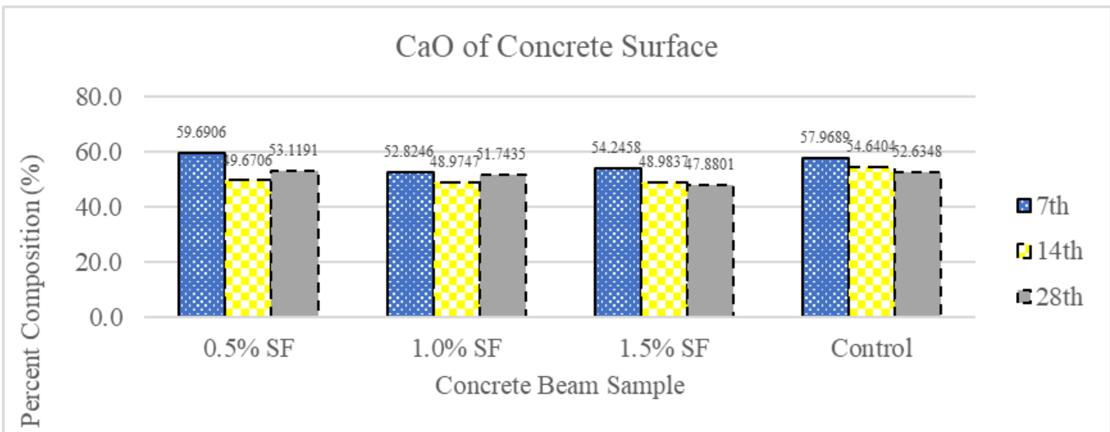


Fig. 5 - Composition of Calcium Oxide, CaO for concrete surface

3.2 Compressive Strength

Referring to BS1881:Part202 [19], the quality of concrete was categorized in 30-40 rebound value which is a good layer of concrete (see table 4). Overall, the pattern of the value of rebound hammer higher on the bottom surface of the beam sample, followed by both sides and lastly lowest value on the surface of the sample. This was justified by the scattered steel fibre that was lumped at the bottom side due to small vibration conducted during the casting. Table 5 shows the result of compressive strength by using the rebound hammer method and an increase trend in RC sample (0.0% steel fibre) was observed and highest strength was found at 0.5% SFRC in fig. 6.

Table 4 - Concrete quality for Rebound Hammer Value (BS 1881, 1986)

Average Rebound Hammer	Concrete Quality
>40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
<20	Poor Concrete
0	Delaminated

Table 5 - Compressive strength (MPa) result by Rebound Hammer method

AGED	SAMPLE No.	0.0% (RC Concrete)	0.5% SFRC	1.0% SFRC	1.5% SFRC
7 Days	Sample 1	32.13	49.51	35.38	38.13
	Sample 2	30.75	48.18	38.13	39.75
	Sample 3	32.38	46.88	36.63	41.00
14 Days	Sample 4	36.50	36.88	35.31	34.14
	Sample 5	38.50	39.00	32.38	31.75
	Sample 6	37.75	38.13	31.19	38.00
28 Days	Sample 7	43.00	38.25	31.13	39.75
	Sample 8	47.00	39.88	34.88	34.13
	Sample 9	45.00	36.50	34.13	40.38

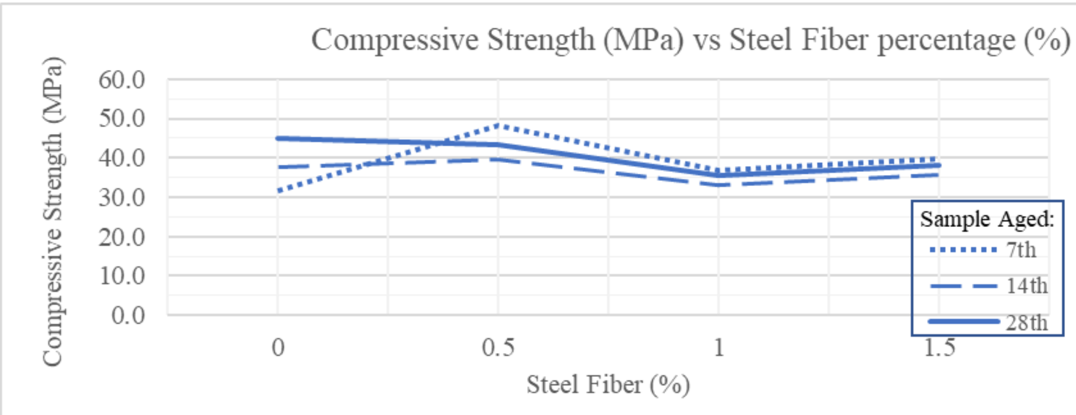


Fig. 6 - The compressive strength (Mpa) vs steel fiber percentage (%)

Universal Testing Machine (UTM) was used to determine the cube compression strength of sample for each concrete mix batched. Table 6 shows the completed result of compression test for the aged concrete sample. The highest compression strength was 1.0% steel fibre portion of SFRC which reached 247.94MPa.

Table 6 - Compression test result

AGED	0.0% (RC Concrete)	0.5% SFRC	1.0% SFRC	1.5% SFRC	Unit
7 Days	119.12	112.70	162.79	86.71	
14 Days	164.93	156.03	225.40	120.05	MPa
28 Days	141.43	171.62	247.94	132.06	

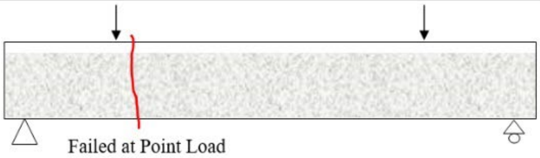
3.3 Flexural Strength

From the flexural test, it was found that the control sample that consists of reinforcement bar has higher strength in resisting load than SFRC sample (see table 7). Carbonation test shows that no corrosion occurred for all samples at early-stage aged of concrete. The samples smooth surface was used to correlate strength by XRF analysis. The flexural test result showed a gradual increase in maximum applied load for 0.5%, 1.0%, 1.5% of percentage of steel fibres and drastically increase for the control sample. For example, 0.5% steel fibre sample can resist load until 25.88kN, 1.0% steel fibre samples until 30.82kN. 1.5% steel fibre until 38.54kN and control sample until 74.51kN. The 0.5% SFRC specimen was totally ruptured. Control sample failed at 74.51kN applied load. Table 8 illustrates the failure condition of the samples; 0.5% steel fibre was split into two divisions as a small portion of steel fibre was considered. 1.0% steel fibre failed with a small intact of the steel fibre between two broken samples. Failure of 1.5% steel fibre showed the grip steel fibre between broken samples. These three samples had shear failure at the point load. For the control sample with reinforcement bar, the failure of this sample was at the support. The crack pattern of the failure can be seen as well for all samples. 1.5% steel fibre sample seemed to have homogeneous steel fibre inside.

Table 7 - Flexural strength test result

SF 0.5%	Day 7			Day 14		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Energy (J)	28.881	4.257	41.677	28.491	38.052	17.384
max Load (kN)	25.879	19.501	21.454	32.73	31.422	21.95
max Stress (kPa)	7.942	7.98	11.688	10.045	12.858	11.958
max Deformation (mm)	3.2	3.6	5.7	4	3.7	3.5
Strain (%)	0.975	0.964	1.476	1.222	0.983	0.898
Time Fail (sec)	12.85	9.8	10.9	16.45	15.8	11.05
Timer (sec)	14	10	12	17	17	12
SF 1.0%	**Day 7**			**Day 14**		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Energy (J)	185.185	34.461	2.265	56.177	13.085	15.971
max Load (kN)	30.817	24.811	18.904	34.874	25.513	18.023
max Stress (kPa)	9.458	10.153	10.299	10.703	10.44	9.819
max Deformation (mm)	13.7	2.8	4.5	7.5	3.7	3.5
Strain (%)	4.195	0.76	1.154	2.313	0.992	0.912
Time Fail (sec)	15.4	12.5	9.45	17.55	12.8	9.15
Timer (sec)	17	13	11	19	14	10
SF 1.5%	**Day 7**			**Day 14**		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Energy (J)	122.523	16.759	39.64	47.789	42.399	36.335
max Load (kN)	38.538	26.297	21.622	34.733	25.608	21.29
max Stress (kPa)	11.827	10.761	11.78	10.66	10.479	11.599
max Deformation (mm)	6.9	3.3	2.9	3.7	4.2	2.6
Strain (%)	2.128	0.889	0.743	1.134	1.13	0.676
Time Fail (sec)	19.2	13.1	10.95	17.35	12.9	10.85
Timer (sec)	20	14	12	18	14	12
CONTROL	**Day 7**			**Day 14**		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Energy (J)	694.36	90.004	248.738			
max Load (kN)	74.514	70.757	70.333			
max Stress (kPa)	22.868	21.715	38.318			
max Deformation (mm)	8	5.4	6			
Strain (%)	2.456	1.662	1.562			
Time Fail (sec)	37.45	35.4	35.05			
Timer (sec)	39	36	36			

Table 8 - Failure condition of samples

Batch	Affected Area Steel Fibre and Reinforcement	Failure of Flexural Test (Case 1)	Sample Condition
0.5% Steel Fibre	 Failed at Point Load		
1.0% Steel Fibre	 Failed at Point Load		
1.5% Steel Fibre	 Failed at Point Load		
Control-reinforcement	 Failed at Support		

3.4 3D Analysis by Design Expert

From the fit statistic in table 9, the F-value and p-value were obtained during the evaluation stage of design analysis. The value of p-value is lesser than 0.05 indicates that the design model analysis was significant [20-21]. In this case, A2 in which compression rebound hammer strength was a significant model term. The p-value of A model is greater than 0.1 indicates that the model is not significant. The model of F-value 5.12 implies for the significant model. There was 0.16% chance for F-value could occur due to noise. The evaluation of the polynomial model needs to refer the aliases to ensure the analysis [20]. The R-squared value of this study was 0.9244, this analysis predicted the R-squared of 0.8399 in reasonable agreement and adjusted R-squared of 0.8982, the difference not exceeded 0.2. The adequate precision of 20.026 indicates that the signal is adequate. As the adequate precision is greater than 4.0 implies that the signal is significant [21].

Table 9 - Fit statistics

Statistics Term	Value
P-value	0.0016
F-value	5.1200
Standard Deviation	0.1809
Mean	0.7500
R-squared	0.9244
Adjusted R-squared	0.8982
Predicted R-squared	0.8399
Adequate Precision	20.0261

The perturbation and interactions of these two factors showed a good correlation when cross joint section supports dependent toward the independent factors. Fig. 7 shows the perturbation graph that indicates good interaction between compression using rebound hammer test (A) and compressive cube strength (B) when the lines intercepted each other. The interaction of all factors was analyzed. Fig. 8 visualized the 3D surface analysis for both factors' compression strength against steel fibre percentage. Optimization between the factors and the responses were considered. The upper limit and lower limit were set for a certain range or any optimization in which maximum or minimum value was required. Lastly, the numerical optimization provided the insight with graphical combination. The optimization result showed in fig. 9 at 0.42% steel fibre, 40.47 MPa compression Rebound Hammer strength and 230.28 MPa compression cube test. The coverage by yellow color indicated for this study implementation while left and right for less than 0.0% steel fibre and top bottom for steel fibre exceed from 1.5%.

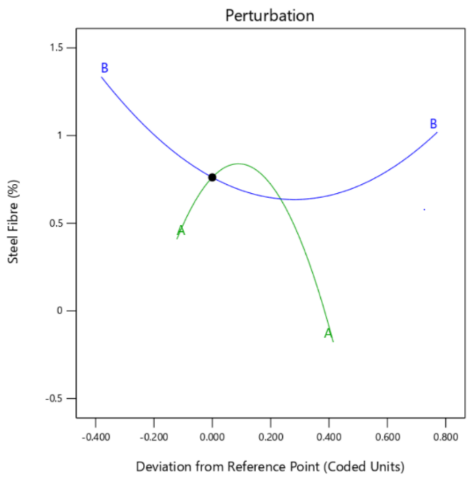


Fig. 7 - The interaction of perturbation

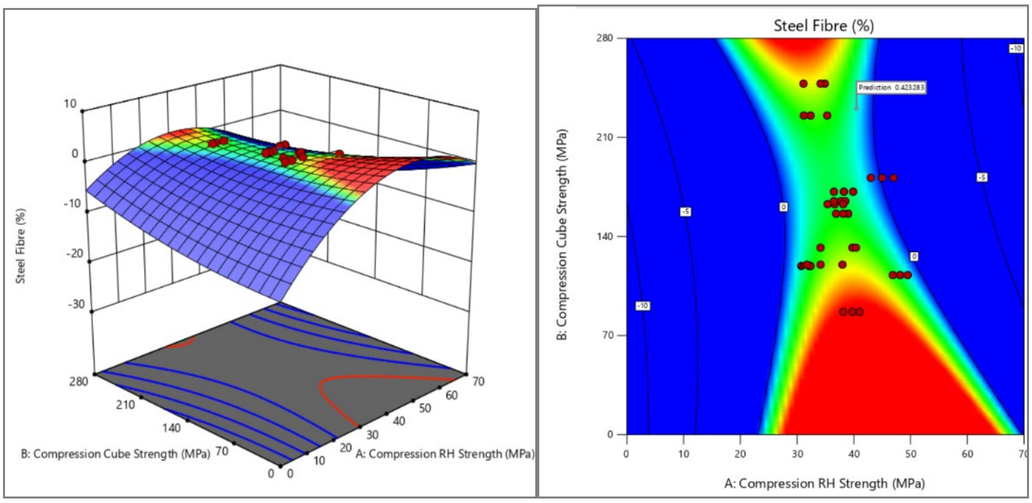


Fig. 8 - 3D Surface analysis

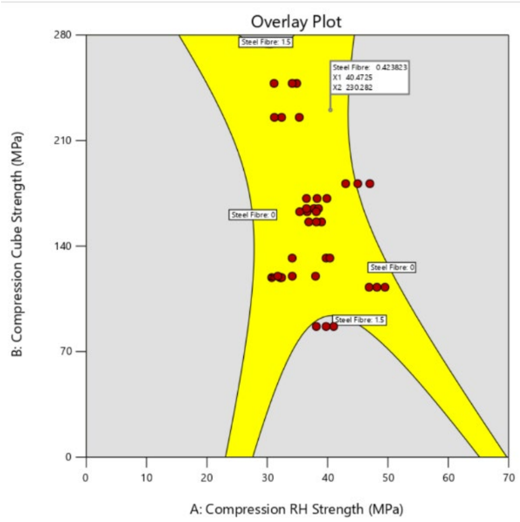


Fig. 9 - Prediction for optimization correlation

3.5 Ultimate Load

From the compressive strength result, the highest compressive strength reached 49.51 MPa for 0.5% SFRC (Rebound Hammer method) and 247.94 MPa for 1.0% SFRC (Universal Testing Machine). Whereas, from the 3D analysis the optimum result was 0.42% SFRC. Therefore, 0.42-1.0% percentage of steel fibre is recommended to obtain optimum result in SFRC.

4. Conclusions

Based on this research study, it can be concluded from the elemental composition analysis, the addition of steel fibre in reinforced concrete beam shows stable composition. The main composition in the concrete, which is calcium oxide, CaO was about 10% difference than the ASTM range, but it is still the highest composition of the element. Other compositions in the observed sample are; Fe2O3, CaO, Al2O3, MgO, while MnO value is relatively low and sometimes cannot be detected. This indicates that the early aged concrete structure specimen was free from any contaminants reaction or no corrosion Iron(III) oxide, Fe3O2 occurred. The XRF test that determines the composition of the sample element, provide benefits in terms of time and cost reduction. This study discussed the use of a portable XRF analyser to support analysis in the experimental testing results.

The flexural strength and compressive strength by compression cube test and rebound hammer test of the samples were determined. From the analysis, the RC specimens can resist higher applied flexural test load as compared to SFRC specimens. During the testing, the failure of the SFRC specimen shows the hairline crack on the load applied before rupture. All specimens reached compressive strength of 40-50N/mm^2. The percentage of steel fibre added into the concrete affect the compressive strength test result. The SFRC specimens simply failed with a small amount of load, but the hairline crack hint was formed at first before failed. The optimum dosage at 0.5% SFRC for the highest compressive strength of 49.51 MPa for rebound hammer test, whereas for the compressive test, 1.0% steel fibre portion of SFRC which reached 247.94MPa was the optimum dosage. The results showed that the addition of steel fibre causes the reduction of slump value (workability). The role of steel fiber might not always involve an increase in SFRC strength but it might has favorable effect on other areas. Nevertheless, the compressive strength and rebound hammer number can be correlated stastically as well as flexural strength and rebound hammer number, in which, compressive and flexural strength can be predicted afterwards and the relationship between the compressive and flexural strength can be presented, but it is not shown in this study.

The compressive strengths with 3D analysis using Stat-Ease Design-Expert can be correlated with experimental result. The compressive strength factors in the aged sample and steel fibre were proven to be to significantly affecting the factors and response. The perturbation and interaction of the two factors were significant. The pattern of rebound hammer compression strength high strength for 0.0%, decrease for 0.5%, 1.0% and strength increased for 1.5% of steel fibre dosage. Showing that u-shaped pattern while cube test highest value for 1.0% steel fibre might be due to vibration. The optimization result showed at 0.42% steel fibre, 40.47 MPa compression Rebound Hammer strength and 230.28 MPa compression cube test. Therefore, 0.42-1.0% percentage of steel fibre is recommended to obtain optimum result in SFRC.

Acknowledgement

The authors would like to acknowledge the financial support for this study from Ministry of Higher Education - Fundamental Research Grant Scheme of 600-IRMI/FRGS 5/3 (178/2019) and other supports from Institute for Infrastructure Engineering and Sustainable Management (IIESM), School of Civil Engineering and Research Management Centre (RMC), UiTM Shah Alam, Selangor, Malaysia. These supports are gratefully acknowledged.

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