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Selecting of an Appropriate Percentage of Material to Prepare Engineering Cementitious Composites using Taguchi Method and Novel Waste Agricultural Fiber

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Abstract - *In this paper Karkade (hibiscus sabdriffa L.) waste fiber was used to prepare engineering cementitious composites. Taguchi method for design of experiments was used to prepare the experimental program. Compressive, flexure and impact strength tests were conducted, the results obtained, analysed and discussed according to tables and graphs obtained from Minitab program. According to Taguchi method, the optimum condition for each test was reported. It was found that the most dominant factor that controlled the test results was W/C ratio followed by fiber content. This is a rational outcome that is consist with previous studies. Also, the optimum condition for each one of the three properties was determined using Taguchi method.*

Key Words: Karkade Fiber, Agricultural Waste, Engineering Cementitious Composites, Taguchi, Mechanical properties.

1. INTRODUCTION

Over the years, natural fibres have proven the quality of their properties, strength and durability, as well as their potential to be used in many industrial applications. In general, the plants from which natural fibres are extracted are divided into two types, primary and secondary plants. Plants like kenaf, flax and sisal are primarily grown to extract the fibres from them. Palm, Coconut and Karkade fibres are extracted after the fruits are taken from the plant. Hence these are called secondary plants, and that's why their fibers are named waste fibres. Its a fact that waste can cause many environmental problems if it is not handled well. Therefore, the reprocess of waste in various industries has become a trend [1]. Many researchers have concluded that cellulose fibers have the potential to act as reinforcement when used with polymer or in fiber cement composites, due to their availability, good properties, eco-friendly and additional significant feature which is low production cost [2,3]. Many types of natural fibers have been used in industrial application. Coconut fibers have been used for the heat insulator, and with rice husk ash in concrete. Also, banana fiber has been used as fillers into polymers composites. Furthermore, coconut fibers oil palm fiber, bamboo fibers, rice-husks and sugar cane were used in fiber cement boards [4][5][6]. The annual global production of agricultural waste is close to a thousand tons. This large amount will have a huge impact if recycled properly [7]. Steps are accelerating in the track of substituting the traditional materials used in cement boards manufacture like synthetic fiber and polymer with natural fibers [8]. Noura et al [8] used rice-husk and old newspapers to prepare fiber-cement panels. Many samples prepared with different percentage of fiber, subjected to different mechanical and physical tests. As a result of their study, bulk density became lighter when fiber percentage increased. Also, flexural strength increased with increasing fiber content, while compressive strength decreased [8]. Rice-husk was also used with sugar cane, bamboo and coconut fiber to produce fiber cement boards used in building panels. The results showed improvement in flexural strength, thermal conductivity and impact strength, while there is no improvement in compressive strength. Mahzabin et al [9] organized a study to assess the effect of chemically treating wood used in cement boards. Three different chemical additives were used. The results showed improvement in properties of treated fiber [9]. A novel composite material known as Engineered Cementitious Composites (ECC) was investigated by University of Michigan. This material was classified as similar in properties to medium to high strength concrete. ECC contains all components of concrete except coarse aggregates. Fibers were used to improve the behavior of the structural member, and to introduce a highly ductile of material [11,12]. Boughanem et al,[10] conducted a study to examine a number of factors that affect the performance of engineering cementitious composite materials, their results showed improvement in mechanical behaviour of samples [10]. On the other hand, Taguchi method of design of experiment developed by Taguchi is provides a simplified and effective method for designing experiments and analyzing the effect of control factor on material performance. Taguchi method showed a significant reduction in the number of experiments compared to other experimental design [13][14]. This study was conducted to characterise and asses the properties of Karkade fiber used to produce engineering cementitious composite by using Taguchi method for design of experiments. The properties measured in this study are compressive, flexural and impact strength.

2. Materials and Methods

2.1 Materials

Karkade Fibers

Karkade (Hibiscus Sabdariffa L.) waste fiber was collected from North Kordofan State-Sudan. Then it was extracted using water retting process. Stem was washed using clean water, then fiber was removed manually, dried in sun light. The length of fiber ranged between 0.5m-1m, and the diameter was about 110micron. The density of fiber was 1.56g/cm^3. Karkade fiber was then cut into small sizes 20mm-40mm for preparing samples and conducting tests (fig-1).

Cement and Fly Ash

Cement 32.5R Type was used in this study with specific gravity 3.02 and fineness 3551 cm^2/g. The properties of cement and fly ash used in this study was stated in Table (1).

Table -1: Chemical Composition of Cement and Fly Ash

Chemical Composition	Cement Grade 32.5	Fly Ash
SiO_2	20.14	58.53
CaO	61.71	5.11
Al_2O_3	5.12	21.6
Fe_2O_3	3.56	6.62
MgO	2.03	2.23
K_2O	0.93	2.25
SO_3	2.83	0.83
Cl	.005	.0051
Na_2O	0.65	0.44

Super Plasticizers

All cementitious samples contained 0.2% Master Glenium150 super plasticizer

Fig -1: Karkade Fiber

2.2 Taguchi Method

The Taguchi method is based on creating an orthogonal array with many control factors and different levels, the factors are classified into: [15]

1. Control factors, that can be controlled.
2. Noise factors, that cannot be controlled.

The orthogonal array can be used depending on control factors and their levels as shown in Table (2). Noise factors affect the target value, and make a quality which is characterised by loss function. Dr. Taguchi transformed this loss function into signal-to-noise ratio which measures how the response varies relative to the nominal or target value under different noise conditions. Signal-to-noise ratio had three categories [15][16].

1. Maximum is better, used when the goal is maximizing the response
2. Minimum is better, used when the goal is minimizing the response
3. Nominal is better, used when the goal is dropping variability around a target value

Table-2: orthogonal array designed by Dr. Taguchi [17]

Control factors	levels			
	2	3	4	5
2	L4	L9	L16	L25
3	L4	L9	L16	L25
4	L8	L9	L16	L25
5	L8	L18	L16	L25

Depending on the objective of this research, three factors and two levels are chosen to make L4 orthogonal array as shown Table (3).

Factors and levels:

1. Karkade fiber content (A) (2%, 4%)
2. Water cement ratio (B) (0.6, 0.65)
3. Karkade fiber length (C) (20mm, 40mm)

Table -3: orthogonal array for experiments

Karkade fiber content(A)	Water cement ratio(B)	Karkade fiber length(C)
2%	0.6	20mm
2%	0.65	40mm
4%	0.6	40mm
4%	0.65	20mm

The larger is the better condition of S/N ratio was used due to the objective of this research of maximizing the mechanical properties of samples. The equation used to calculate this condition is stated below.

$$SN_L = 10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where n is the number of replications; yi is the observed response value, and i = 1, 2, ..., n.

2.3 Mix Design

After selecting Taguchi L4 orthogonal array, the mix design for samples was prepared as follows:

Fiber content was 2% and 4% by weight, cement/ fly ash ratio was 1:1 by weight and W/C ratio was 0.6 and 0.65. The cement, fly ash, fiber and super plasticizer were added gradually using mechanical mixer. For each series, samples were prepared with dimensions of 50mmx50mmx50mm for compression, 300mmx150mmx20mm for flexure and 80mmx20mmx20mm for impact fig (2). All samples cured in water for 28days before testing.

Fig (2) a. Samples after curing, b. Compression and bending machine, c. Impact machine

3. Results and Discussion

Compression, flexure and impact tests were conducted on samples after 28 days according to ASTM-D1037, ASTM-C1185 and ASTM-D256 respectively, and the results were shown in Table (4).

Table-4: Test results and S/N ratio

Fiber Content	W/C	Fiber Length	Comp-Strength (Mpa)	Bending Strength (Mpa)	Impact Strength joul
2	0.6	20mm	43.87	3.4	7.33
2	0.65	40mm	39.95	2.8	8.83
4	0.6	40mm	42.09	6.05	8.58
4	0.65	20mm	37.93	3.05	8.42

S/N Ratio Compression	S/N Ratio Bending	S/N Ratio Impact
32.84335269	10.62958	17.30208
32.03033567	8.943161	18.91921
32.48357851	15.63511	18.66975
31.57965685	9.685997	18.50624

From the above table and according to S/N ratio largest is better, it can be observed that the maximum value of compressive strength was obtained from the first trial, while the maximum flexure value was obtained from the third trial, and the maximum value of impact obtained from the second trial. The factor that controls the results was determined based on the difference between the highest and the lowest S/N ratio. The larger the difference, the greater the effect of the factor. According to this and with reference to tables (5,6,7) it can be reported that, for compressive strength and flexure strength the dominant factor that has highest influence is w/c ratio, followed by fiber content, while in impact strength the control factor was fiber length, followed by w/c ratio.

Table-5: Response table for S/N ratio for compressive

levels	FIBER CONTENT	W/C	FIBER LENGTH
1	32.44	32.66	32.21
2	32.03	31.8	32.26
Delta	0.41	0.86	0.05
Rank	2	1	3

Table-6: Response table for S/N ratio for bending

levels	FIBER CONTENT	W/C	FIBER LENGTH
1	9.786	13.132	10.158
2	12.661	9.315	12.289
Delta	2.874	3.818	2.131
Rank	2	1	3

Table-7: Response table for S/N ratio for impact

levels	FIBER CONTENT	W/C	FIBER LENGTH
1	18.11	17.99	17.9
2	18.59	18.71	18.79
Delta	0.48	0.73	0.89
Rank	3	2	1

3.1Determination of appropriate mixing parameter

Compressive Strength

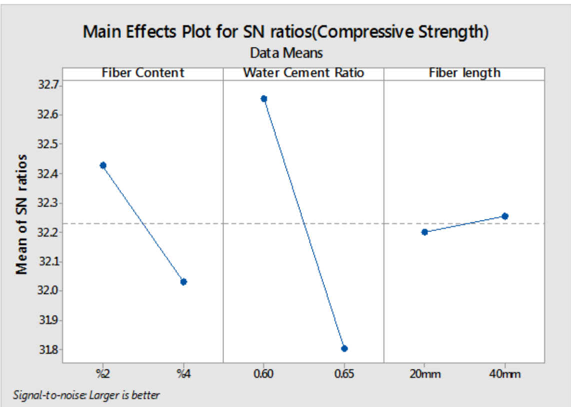
The larger is better S/N ratio was used to determine the maximum compressive strength of samples, from fig (3.a) it can be observed that, the 2% of fiber content, 0.6 of w/c ratio and 40mm fiber length give highest results. Hence the optimum condition for compressive strength was found to be (2% of fiber content, 0.6 w/c ratio and 40mm fiber length).

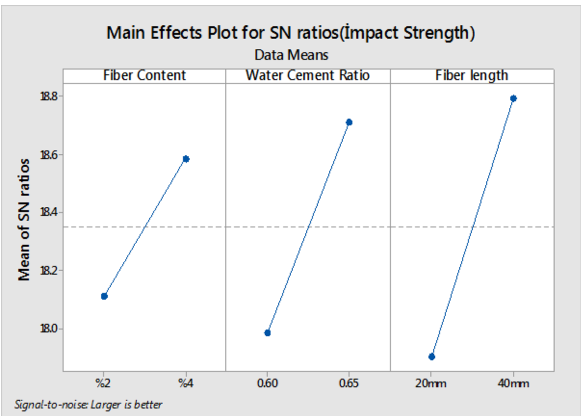
Flexure Strength

Also, the larger is better S/N ratio was used to determine the maximum flexure strength of samples. Again, from fig (3.c) it can be seen that, the 4% of fiber content, 0.6 w/c ratio and 40mm fiber length give highest results. Thus, the optimum condition for flexure strength was found to be (4% of fiber content, 0.6 w/c ratio and 40mm fiber length)

Impact Strength

As in compression and flexure, the larger is better S/N ratio was used to determine the maximum impact strength of samples. From fig (3.b) it can be observed that, the 4% of fiber content, 0.65 w/c ratio and 40mm fiber length give highest results. Thus, the optimum condition for impact strength was found to be (2% of fiber content, 0.65 w/c ratio and 40mm fiber length)





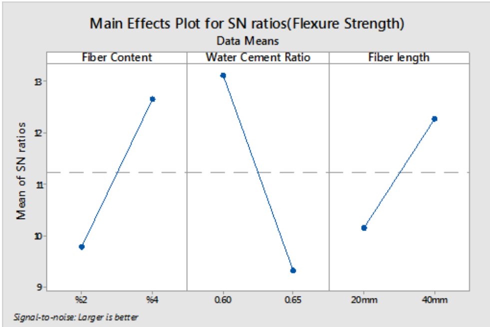


Fig.3 mean of S/N ratio a. compression, b. impact, c. flexure

4. CONCLUSIONS

This study was conducted to determine the appropriate percentage of materials used to prepare engineering cementitious material. In this study Karkade waste natural fiber was used and experimental design method (Taguchi L4) with three factors and two levels was performed to design the experiment. Compressive, flexure and impact tests were conducted, and according to Taguchi method, the optimum condition for each test was reported. For compression (A1, B1, C2), for flexure (A2, B1, C2), for impact (A1, B2, C2). The most dominant factor that controlled the test results was w/c ratio followed by fiber content, and this is a rational outcome that is consistent with previous studies

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