# The effect of different accelerated aging methods on properties of sisal fiber reinforced concrete with and without metakaolinite

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***Abstract:***
*The effect of accelerated aging methods on sisal fiber reinforced concrete with and without metakaolinite has been investigated through a number of tests. The properties investigated include compressive strength, flexural strength, splitting tensile strength and pH-value. Sisal fiber has been used at three percentages of total mixture volume (0.6, 1.20 and 1.8%), while the metakaolinite has been added in (10, 30 and 50%) as a partial replacement by weight of cement. The results of this study show that the mechanical strength of fiber reinforced concrete with and without metakaoline decrease as the exposure period of wetting and drying is increase. The maximum reduction in mechanical strengths for MF1.2, 30 after 15-cycles of wetting-drying conditions was 35.53, 6.7 and 16.2 % for compression, flexural and splitting strength respectively compared with 5-cycles of wetting-drying conditions. The hot-water soak method considered as an accelerated aging and not influence significantly on the mechanical strength of plain concrete, fiber reinforced concrete with and without metakaoline. The important observation from this study is the reduction in pH-level of plain and fiber reinforced concrete due to the incorporation of metakaoline as a partial replacement by weight of cement and as a result of this reduction the mechanical strength of sisal fiber reinforced concrete exposed to various conditions (wetting-drying and hot water) enhanced and improved by incorporation 30% of metakaoline (by weight of cement).*

**Keywords:** *sisal fiber, metakaolinite, accelerated aging.*

## I. INTRODUCTION

Concrete is the most versatile material used in civil engineering structures. It is so simple and cheap that it can so easily be made by mixing aggregates, water and cement with unsophisticated equipment. Then, this mixture is poured or pumped virtually into any shape or section. Concrete is relatively strong in compression but weak in tension and tends to have brittle properties, because of the micro-cracks between the aggregate and the cement paste which tend to extend and contact with adjacent cracks when exposed to any tensile stress. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers [1]. The concept of using fibers to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair to reinforce plaster and asbestos to reinforce pottery, use of continuous reinforcement in concrete (reinforced concrete) increases strength and ductility, but requires careful placement and labor skill [2].

Recently, there has been resurgence of interest in using natural fibers of vegetable origin which are constituted of cellulose for fiber reinforcement of concrete in developing countries. This has been brought about by the energy crisis, a general oversupply and relatively cheap source of fibers and the need to reduce foreign reserve expenditure on importing other fibers.

The investigations on the long term performance of natural fiber reinforced concrete are very important, since these fibers are liable to degradation in cement environment and exposure to natural weathering. One of the common ways of evaluating the long term performance of a fiber reinforced composite is to determine the development in the performance of the composite over several years in water or after a certain period of accelerated aging treatment [3]. Accelerated methods for the aging of cellulose fiber composite were developed in order to study three main topics [4]:-

1. Characterization of the effect of natural aging and various accelerated aging treatments on the changes in mechanical properties.
2. Characterization of the effect of the various aging conditions on changes in the properties of the fibers, which affect the performance of whole composite.
3. Characterization of the various aging conditions on the fiber-matrix interface to resolve the influence of interfacial effects on the long term performance.

Many researchers studied these main topics starting with Gram [5], he used special methods which is called climate cubical where the specimen was subjected to moisture and cooling by spraying in water and then subjected to a heater air with a temperature of 105°C for 5.5 hours. The conditions are that the cycle involves repeated exposure to rain and sunshine. He also immersed specimens of fiber reinforced concrete in a water bath with a temperature of +50°C up to 2 years. This condition was expected to provide an accelerated aging of the composite which was developed in connection with the production of an alkali-resistance glass fiber, While Soroushine and Marikunte [6] used climate box for accelerating the aging of cellulose fiber reinforced composite. The conditioning cycle involves 0.5 hour for spraying the specimens with water then dried them at +82°C for 5.5 hours.

Sisal fiber reinforced composites were subjected to two aging methods by Bergstrom and Gram [7].The first one is called the BRE-method, which includes the storage of the composite in hot water for different times and temperatures. The second method is called CBI-method. It includes storage of the composite alternately wet and dry.

In another hand date palm frond stalks in hardened concrete were subjected to accelerating aging by Abdul-Rhmann and Alam [8], the conditioning cycle involves immersion in water at room temperature for two hours, wiping off the excess water, then dry in an oven at 100°C for 10 hours.

The aim of this experimental work is to study the effect of accelerated aging on the both sisal fiber reinforced concrete with and without metakaolinite as pozzolanic material. Many tests are required to be assessed in this experimental work such as: compressive strength using (100 mm) cubes, flexural strength using (100 mm ×100 mm × 500 mm) simply supported prisms, splitting tensile strength using (100 mm × 200 mm) cylinders and pH-level test.

In this investigation, the sisal fiber reinforced concrete with and without metakaoline specimens were subjected after 28-day curing in water to two types of accelerated aging test describes as follow [9]: -

1. Hot-water soak method: specimens were immersed in a sealed tank filled with water and thermostatically controlled heater was used to maintain the water at 50°C. The specimens tested after 10, 20 and 30 days.
2. Wetting and drying method: specimens were subjected to wet-dry cycles (48 hours) which involve: 20 hours submerged under water at 20°C; 4 hours dried in air at room temperature; 20 hours in oven at 100°C; 4 hours cool down at room temperature. The specimens tested after 5, 10 and 15-cycles of exposure.

## II. EXPERMENTAL PROGRAM

### 2.1 Materials Used:

Materials used for the production of all concrete mixtures included Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate with a maximum size of 9.5 mm, superplasticizer, sisal fibers and metakaolinite as pozzolanic admixture.

Sisal fiber has been extracted from bundles of 1.5 m length, cut into (40 mm) length as shown in Fig 1 and added at proportions of (0.6, 1.2 and 1.8%, respectively) by volume of total mixture. Table 1 shows some properties of the fiber. The fibers have been washed by tap water and added to the mixture of saturated surface dry conditions.

Metakaolinite is an aluminosilicate pozzolan prepared by heating bad-crystallized and fine grain size of Iraqi kaolin in a fixed-bed furnace at about 800°C. Metakaolinite was added in dry state in (10, 30 and 50%) levels as a partial replacement by weight of cement and thoroughly mixed with it in order to obtain a homogenous mixture. Table 2 and 3 show the chemical and physical properties of metakaolinite respectively. The X-ray analysis of metakaoline is shown in Fig. 2.

**Table 1:** Properties of sisal fiber [15]

| | |
|---|---|
| **Density (g/cm$^3$)** | 1.33 |
| **Tensile Strength (MPa)** | 600-700 |
| **Modulus of elasticity (GPa)** | 38 |
| **Elongation at failure (%)** | 2-3 |
| **Moisture absorption (%)** | 11 |

**Fig. 1:** sisal fibers

**Table 2:** Chemical analysis of metakaolinite

| Oxide | % by weight |
|---|---|
| $SiO_2$ | 62.58 |
| $AL_2O_3$ | 33.4 |
| $Fe_2O_3$ | 1.33 |
| $TiO_2$ | 1.43 |
| CaO | 0.075 |
| MgO | 0.02 |
| $Na_2O$ | 0.03 |
| $K_2O$ | 0.025 |
| L.O.I | 1.0 |

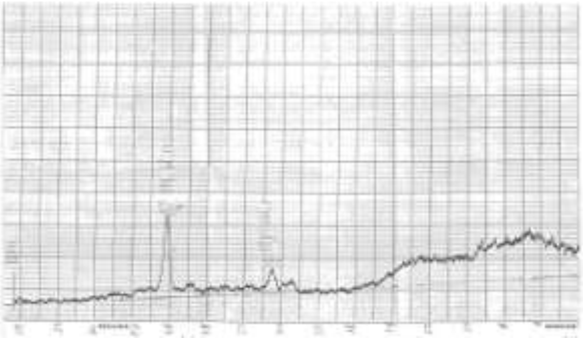

**Fig.2:** X-ray diffraction pattern for metakaolinite

**Table 3:** Physical properties of metakaolinite

| | |
|---|---|
| **Specific gravity** | 2.5 |
| **Particle shape** | hexagonal |
| **Particle size(um)** | 38 |
| **Elongation at failure (%)** | 3 |
| **Form** | amorphous |

## 2.2 Preparation of specimens:

The reference concrete mixture is designed according to the British method B.S. 1881. All mixtures have been designed to have a 28-day cubic compressive strength of 35 MPa. After many trials, one mixture proportion has been used in this study (1:1.36:2.2) (cement: sand: gravel) by weight. Cement content was (440 kg/m$^3$) and w/c ratio was (0.43) to give a slump of (85±5) mm. Super-plasticizer has been used to maintain specific slump for all mixtures. The mixtures have been batched in a rotary mixer of 0.1 m$^3$. The dry constituent cement, sand and aggregate are initially mixed for 1 min then the required amount of water is added and the whole mixture constituents are mixed for another minute. The fibers are then added for a period ranging from 1 to 3 min depending on the amount of fiber. The superplasticizer added in steps, then the whole constituents mixed for proper time until a uniform dispersion of fibers is achieved. Over mixing is avoided because the fiber may suffer damage and loss of strength. Such procedure results in good dispersion of fibers and it prevents balling problems. The fiber reinforced metakaolinite concrete are mixed similarly except that the metakaolinite is mixed with cement, before added into the mixer to ensure uniform dispersion of the admixture. To obtain a fair face casting and to facilitate remolding, the moulds are thoroughly oiled before casting. Casting is carried out for each 50 mm depth of concrete. A vibrating table is used throughout this study. Each layer is vibrated for 20 sec, to avoid any segregation. The surface of the concrete is then struck by using trowel. The specimens are covered with nylon sheets to prevent evaporation of water from concrete and stored under laboratory condition. The specimens are remolded after 24 h and stored in water to have a relatively constant temperature about 21±2°C until the time of testing.

## 2.3 Testing procedure of all mixtures:

The workability of the fresh concrete is measured by using the standard slump test apparatus. The slump test was carried out according to B.S.1881:1952. The internal surface of the mold was thoroughly cleaned and freed from superfluous moisture before conducting the test. The mold was placed on a smooth, horizontal, rigid and non-absorbent surface metal plate and then filled with four layers. Each layer is one-fourth the mold height and was tamped with 25 strokes of the rounded end of a tamping rod. The strokes were distributed in a uniform manner over the cross-section of the mold and for the subsequent layers, penetrated into the underlying layer. The mold was removed from the concrete by raising it in a vertical manner and then allowing the concrete to subside. The slump was then measured immediately by determining the difference between the height of the mold and the highest point of the specimen.

The mechanical tests were including compressive strength test which determined according to B.S.1881: part 116:1989 using 100 mm$^3$. The compressive strength cubes have been tested using (ELE-Digital Elect.2000) at loading rate of 15 MPa/min. Flexural strength has been carried out on (100 mm × 100 mm × 500 mm) simply supported prisms with clear span of 400 mm under one point loading according to B.S.1881: part 112:1989. The splitting tensile strength is determined according to B.S.1881: part117: 1989, using (100 mm × 200 mm) cylinders. The splitting tensile strength cylinders have been tested using (ELE-Digital Elect. 2000). The average splitting strength of three cylinders is recorded for each test.

The pH-level measured by the pH of the solution using a standard testing apparatus (Metro-686), an indication for the pH-level of the different matrices can be obtained. This apparatus transport the chemical effects caused by a specific sample into electrical signals (milivolte). Each sample prepares for pH test with equal weight of ground matrix and deionized water, the pH of results slurry was measured by special glass electrode. To avoid concentration of an alkali layer around the glass electrode, the slurry samples was stirred throughout the test. The average of three samples has been adopted at each test.

## III.EXPERMENTAL RSULTS AND DISCUSSION

The effect of accelerated aging on performance of the sisal fiber reinforced concrete with and without metakaolinite is estimated by determining the compressive strengths, tensile strengths, splitting strengths and pH value

**3.1 Testing of slump:** The slump cone test is adopted to assess the workability of plain and fiber reinforced concrete the test results are presented in Table 4. Regarding the results, it has been seen the following:-

1- As fiber volume fraction increased, the dosage of superplasticizer is increase for fiber reinforced concrete this is due to the high cohesion of mixes containing higher volume fraction, t this concur with observation made by Sarmad and Jorillo [11, 12], they stated that it is necessary to increase either the dosage of water reducing admixture or reducing the proportion of aggregate to keep the workability constant.

2- The dosage of superplasticizer increased as the level of replacement of metakaoline by weight of cement increases for fiber reinforced metakaoline concrete (MF). Gram (8), used the superplasticizer whenever necessary to make the fiber concrete easier to work when using cement substitute or other admixtures.

**Table 4:** Slump test results of fiber reinforced concrete with and without metakaoline

| Mix designation | Vf (%) | Mk (%) | HRWR (%) | Slump (mm) |
|---|---|---|---|---|
| R | 0.0 | 0.0 | 0.0 | 80 |
| SF | 0.6 | 0.0 | 0.47 | 82 |
| | 1.2 | 0.0 | 0.84 | 85 |
| | 1.8 | 0.0 | 2.20 | 80 |
| MF | 0.6 | 10 | 1.72 | 83 |
| | | 30 | 3.17 | 83 |
| | | 50 | 5.12 | 85 |
| | 1.2 | 10 | 2.16 | 82 |
| | | 30 | 3.80 | 83 |
| | | 50 | 5.41 | 80 |
| | 1.8 | 10 | 3.80 | 85 |
| | | 30 | 6.60 | 82 |
| | | 50 | 7.80 | 80 |

**2. Mechanical strength results:** The mechanical strength (compressive, flexural and splitting tensile) tests results are presented in tables 5 and 6 for both types of accelerated aging test results. From these results the following can be observed: -

1. It can be recognized from the results that the mechanical strength of fiber reinforced concrete with and without metakaoline decrease as the exposure period of wetting and drying is increase, this can be attributed to:-

2. The changes in the internal structure of the constituent materials (fibers and cement matrix) similar finding was reported by Gram (8) he claimed that the lignin of the fibers (the glue which binds the individual cells in the fiber together) soften at high temperature and the cement matrix can be changed as a result of the formation of micro cracks due to the rapid cooling and the considerable drying out.

3. Disruption of the bond between the fibers and the matrix this agreed with Aggarwal(18), he found that the reduction in strength indicates the possibility of breakdown of fibers or the bond between the fibers and the matrix.

This to observation is in contrast with Markunte and Soroushian (19), they found that accelerated wetting-drying slightly improves the flexural strength of cellulose fiber reinforced cement composites. The mechanical strength of SF1.2 and MF1.2, 30 mixes higher than R concrete mix, this means that the use of fibers improve the strength of concrete and the durability of the composite can be improved also by partial replacement of cement with 30% of metakaoline by weight.

Table (6) shows that the maximum reduction in compressive strength after 15-cycles of wetting-drying conditions was 6.5, 4.5 and 35.53.4% for R, SF1.2 and MF1.2,30 respectively, and the maximum reduction in flexural strength was 12, 7 and 6.7% for R, SF1.2 and MF1.2,30 respectively, while the maximum reduction in splitting strength was 22.5, 18.4 and 16.2% for R, SF1.2 and MF1.2,30 respectively, and all compared with 5-cycles of wetting-drying conditions.

1- From the test results presented in table 6 it is noticed that the mechanical strength increased as the period of soaking in hot water increased for plain concrete and fiber reinforced concrete with and without metakaoline, this can be attributed to the densification of the interface between the fiber and the matrix with cement hydration products for fiber reinforced concrete and pozzolanic reaction products for fiber reinforced metakaoline concrete. This observation confirm with Soroushine and Markunte(9). Table 8 shows that the maximum increase in compressive strength after a soaking period of 30 days in hot water was 50.5, 68.6 and 76% for SF1.2 and MF1.2, 30 respectively, and the maximum increase in flexural strength was 3.8, 4.2 and 5%

for SF1.2 andMF1.2, 30 respectively, while the maximum increase in splitting strength was 7.63, 12 and 16.72% for SF1.2 andMF1.2, 30 respectively, and all compared with a soaking period of 10 days in a hot water.

2- It is obvious from the test results presented in tables 5 and 6 that there is slightly changes in the mechanical strength of the plain concrete and fiber reinforced concrete with and without metakaoline after exposure period to 15 cycles of wetting-drying conditions and after a soaking period of 30 days in a hot water. This observation concur with Sharman and Vantier(14), they found that the strength of specimens exposed to hot water-soak method increase up to 20 days but no further changes was evident between 20 and 350 days, and for specimens exposed to 0 and 10 cycles of wetting and drying there is no further change between 10 and 50 cycles.

**3. pH-level test results: -** The pH-level test results are presented in table 7, from these results it can be clearly noticed the following: -

1. The incorporation of metakaoline reduces the pH-level of plain concrete after 15-cycles of wetting-drying and after 30 days of soaking in a hot water.
2. The reduction in pH-level was higher for fiber reinforced concrete with 30% of metakaolinite replacement specimens soaked in hot water (11%) compared with those exposed to wetting-drying cycles (9%) and all compared with plain concrete, this is due to the higher pozzolanic reaction which tend to reduce the CH content in the matrix.

**Table 5:** Mechanical strength results of plain and sisal fiber reinforced Concrete with and without metakaoline exposed to wetting-drying conditions

| Mix | Compressive strength (MPa) | | | Flexural strength (MPa) | | | Splitting tensile strength (MPa) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Exposure period (cycles) | | | | | | | | |
| | 5 | 10 | 15 | 5 | 10 | 15 | 5 | 10 | 15 |
| **R** | 36.8 | 34.8 | 34.4 | 3.68 | 3.4 | 3.24 | 2.13 | 1.73 | 1.65 |
| **SF0.6** | 35.6 | 34.4 | 33.8 | 4 | 3.8 | 3.72 | 2.47 | 2.12 | 2.02 |
| **SF1.2** | 40.1 | 38.7 | 38.3 | 4.8 | 4.55 | 4.46 | 2.77 | 2.37 | 2.26 |
| **SF1.8** | 37.8 | 36.5 | 36.1 | 4.4 | 4.18 | 4.1 | 2.62 | 2.25 | 2.15 |
| **MF0.6,10** | 35.7 | 34.5 | 34.2 | 3.88 | 3.68 | 3.61 | 2.36 | 2.03 | 1.93 |
| **MF0.6,30** | 36.2 | 35.4 | 34.7 | 4.3 | 4.07 | 4.00 | 2.61 | 2.24 | 2.14 |
| **MF0.6,50** | 34.8 | 33.6 | 33.4 | 3.2 | 3.03 | 2.98 | 1.88 | 1.62 | 1.54 |
| **MF1.2,10** | 39.4 | 38.2 | 38 | 4.6 | 4.4 | 4.2 | 2.61 | 2.29 | 2.20 |
| **MF1.2,30** | 40.8 | 39.6 | 39.4 | 5.08 | 4.84 | 4.74 | 2.9 | 2.54 | 2.43 |
| **MF1.2,50** | 37.6 | 36.5 | 36.3 | 3.8 | 3.6 | 3.54 | 2.14 | 1.88 | 1.79 |
| **MF1.8,10** | 38.4 | 37.6 | 37.4 | 4.32 | 4.15 | 4.10 | 2.52 | 2.27 | 2.19 |
| **MF1.8,30** | 39.2 | 38.4 | 38.2 | 4.68 | 4.50 | 4.45 | 2.68 | 2.41 | 2.33 |
| **MF1.8,50** | 36.7 | 36 | 35.7 | 3.52 | 3.38 | 3.34 | 2.04 | 1.84 | 1.77 |

**Table 6:** Mechanical strength results of plain and sisal fiber reinforced concrete with and without metakaoline soaked in hot water

| Mix | Compressive strength (MPa) | | | Flexural strength (MPa) | | | Splitting tensile strength (MPa) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Exposure period (days) | | | | | | | | |
| | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 |
| **R** | 39.6 | 41.2 | 41.6 | 4.15 | 4.26 | 4.31 | 2.62 | 2.77 | 2.82 |
| **SF0.6** | 42.8 | 44.3 | 45.7 | 4.8 | 4.89 | 4.99 | 2.94 | 3.23 | 3.30 |
| **SF1.2** | 48.1 | 49.8 | 51.4 | 5.76 | 5.87 | 6.00 | 3.32 | 3.67 | 3.72 |
| **SF1.8** | 45.6 | 47.2 | 48.7 | 5.32 | 5.43 | 5.53 | 3.13 | 3.44 | 3.51 |
| **MF0.6,10** | 43 | 44.7 | 46.4 | 4.64 | 4.78 | 4.89 | 2.71 | 3.14 | 3.19 |
| **MF0.6,30** | 43.5 | 45.2 | 47.0 | 5.12 | 5.27 | 5.40 | 3.00 | 3.48 | 3.54 |
| **MF0.6,50** | 42.1 | 43.8 | 45.5 | 3.82 | 3.93 | 4.03 | 2.16 | 2.50 | 2.55 |
| **MF1.2,10** | 47.1 | 49.0 | 50.8 | 5.49 | 5.63 | 5.76 | 3.00 | 3.39 | 3.48 |
| **MF1.2,30** | 48.7 | 50.4 | 52.4 | 6.00 | 6.16 | 6.3 | 3.35 | 3.8 | 3.91 |
| **MF1.2,50** | 45.1 | 47.0 | 48.7 | 4.61 | 4.73 | 4.84 | 2.46 | 2.77 | 2.85 |
| **MF1.8,10** | 46 | 47.8 | 49.7 | 5.17 | 5.27 | 5.40 | 2.89 | 3.18 | 3.26 |
| **MF1.8,30** | 46.8 | 48.7 | 50.5 | 5.61 | 5.72 | 5.86 | 3.08 | 3.38 | 3.48 |
| **MF1.8,50** | 44.1 | 45.8 | 47.6 | 4.21 | 4.30 | 4.40 | 2.34 | 2.57 | 2.64 |

**Table 7:** pH-level results of plain and sisal fiber reinforced concrete with metakaolin exposed to wetting-drying conditions and soaked in hot water

| Mix | pH-Value | |
|---|---|---|
| | Exposure period | |
| | 15-cycles wetting and drying | 30-days soaked in hot water |
| **R** | 12.2 | 12 |
| **MF10** | 11.9 | 11.53 |
| **MF30** | 11.2 | 10.82 |
| **MF50** | 10.8 | 10.43 |

## IV. CONCLUSION

1- The addition of fiber reduces the workability of all concrete mixtures. To compensate for the reduction in workability, superplasticizer is used in different dosages between 0.47 to 2.2% for SF concrete mixtures.

2- The dosage of superplasticizer increased as the level of replacement of metakaoline by weight of cement increases for fiber reinforced metakaoline.

3- There is a remarkable reduction in mechanical strength of plain concrete, fiber reinforced concrete and fiber reinforced metakaoline concrete as the cycles of wetting and drying increased.

4- The hot-water soak method considered as an accelerated aging and not influence significantly on the mechanical strength of plain concrete, fiber reinforced concrete and fiber reinforced metakaoline concrete.

5- The durability and mechanical strength of sisal fiber reinforced concrete exposed to various conditions (wetting-drying and hot water) enhanced and improved by incorporation 30% of metakaoline (by weight of cement) as a result of reducing the alkalinity of the matrix.

6- The incorporation of metakaoline as a partial replacement by weight of cement will reduce the pH-level of plain concrete.

Abbreviation:-

**R:** reference concrete
**VF:** volume fraction
**HRWR:** high range water reducers
**SF**: sisal fiber reinforced concrete.
**MF**: metakaolinte fiber reinforced concrete

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