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Performance of concrete beams reinforced with fiber ropes as a partial replacement of steel bars

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Abstract*— Fiber ropes such as sisal and flax, characterized by their high tensile strength, light weight and low cost, can be utilized as a partial replacement of steel bars to reduce the construction cost. Present research is a new approach to utilize sisal and flax ropes (processed with kimapoxy 150) as a partial replacement (25, 50, 75, 100%) of steel bars. Nine beams with a cross section 250x300 mm2 and 2000 mm length are prepared for a flexural test with 1800 mm clear span. The beams were supported with steel bars partially replaced with sisal or flax ropes. Different tests were carried out on the beams to study the performance of alternative beams incorporating sisal and flax ropes as a partial replacement of steel. It was observed that applying up to 50% fiber ropes enhanced the deformation capacity factor (DCF), the same Load capacity factor (LCF) and the serviceability factor (SF) are preserved and realized about 75% of the load capacity of the control beam (reinforced with steel only). Utilizing fiber ropes in concrete can reduce buildings cost in developing countries.

Keyword: **Reinforcement, Sisal and Flax Ropes, Flexural Test; Load Capacity Factor, Deformation Capacity Factor, Serviceability Factor.**

I. INTRODUCTION

In many developed and developing countries, the cost of building materials in concrete constructions, especially steel, is a severe problem. The objective of this paper is to investigate the possibility of utilizing various types of natural fibers (sisal and flax) processed with kimapoxy 150 as a partial substitution of steel bar reinforcement in reinforced concrete structures. Many research studied some alternatives for steel reinforcement, but none of them employed natural textile ropes (as flax) for this purpose. Recently, few researchers investigated using sisal ropes as the full replacement of steel bars.

Sisal fiber fortified composite, bamboo fiber strengthened composite, coir strengthened composite and jute fiber fortified composite have high-quality effects in addition to their moderate elastic and flexural features when compared with different lignocelluloses strands. As a result, the utilization of normal filaments, as sisal strands, bamboo strands, coir filaments and jute strands, is preferred for being locally accessible [1]. Pumice and sisal plants are available in tropical countries. Such natural materials are very good strengthening components in polymeric composites for their lightweight and high strength. This study aimed at investigating the effect of using sisal fibers as a replacement of steel bars in a simple concrete structural element. The behavior of sisal fiber reinforcement of lightweight concrete beam with pumice as rough mass is examined under flexural loading. In order to enhance the performance of sisal reinforcement [2], any change of the reinforcement will be determined. Utilizing fiber reinforced polymer (FRP) in fortified cement has advantages that depend upon certain elements such as shape, length, cross-segment, fiber substance and bond attributes of FRP [3].

Flax fibers are new materials with high mechanical properties and may be a good replacement of glass fibers reinforcement in the composite. However, the main disadvantage of flax fibers is the changeability of their properties since environmental effects (e.g. high relative humidity) [4] may increase stretchy strength and strain of flax fibers. In addition, their strength decreases with the increase of the fiber length, fiber diameter and gauge length [5]. However, the use of sisal as reinforcement in the cement based matrix has proved to be promising [6]. Fibers can increase both the strength and the toughness of the composite. Thus, fibers are added in components such as slabs and pavements to control cracking caused by humidity or temperature changes. The fibers work in such applications, as secondary reinforcements. Vegetable fibers, including sisal, flax, coconut, jute, bamboo and wood fibers, are forthcoming reinforcing materials, but their use is still empirical [7]. Most plant fibers are hydrophilic in nature, and water absorption may be very high and this can be controlled by different methods of surface modification. As a result of the low density and high specific strength and modulus, sisal fiber is a possible resource material for various engineering applications such as electrical and packaging industries as well as in automobiles, railways, building, geotextile and defense [8-10].

II. RESEARCH SIGNIFICANCE

This research aimed at examining the possibility of utilizing sisal and flax ropes to the reinforced concrete structure for their high tensile strength, low weight and cheap cost. The main reason behind using sisal and flax ropes in concrete is to avoid rusting and erosion and to be full reinforcement as well. The main goal of the research is studying the behavior of beams reinforced with sisal or flax ropes compared to those, which contain steel bars.

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III. EXPERIMENTAL WORK

A group of destructive tests are carried out on concrete elements (cylinders and beams) which integrate sisal or flax ropes as a partial replacement of steel bars to study the performance of the replacement and compare the test results with control beams which use steel bars only as reinforcement. Nine beams with dimensions 250x300x2000 mm with a clear span 1800 mm were prepared in order to study the flexural strength of beams that contains fiber ropes whereas 9 cylinders with dimensions 150x300 mm that contains 3 types of reinforcement (steel, sisal and flax) in order to study the pull-out test.

IV. RESEARCH SIGNIFICANCE

A. Materials

Ordinary Portland cement was used, and testing of cement was carried out according to the Egyptian Standard Specification [11]. Natural sand composed of siliceous materials was used as Fine Aggregate (FA), and sand testing was carried out according to the specifications [12]. Specific Weight of the used sand is 2.6 with a bulk density of 1.78 t/m^3 [13]. Moreover, coarse aggregate (CA) is used as gravel aggregate, and the testing of gravel aggregate was carried out according to the [12], and the specific weight of used gravel was 2.64 and its bulk density is 1.56 t/m^3 [12]. Drinking water is used for mixing, and Sikament 163 (Complies with ASTM C 494 type f, B.S.5075 PART 3) was used to achieve a slump value of (10-12) cm.

Egyptian locally produced agricultural sisal or flax fiber ropes (12 mm diameter) are supplied from the Textile Consolidation Fund TCF, Alexandria, Egypt and necessary tests of ropes were carried out. Firstly, humidity content of Libeccio instrument, as illustrated in Table 1, was determined. Secondly, fiber tensile strength was measured by Pressley tester [13] as shown in Fig. (1) and Table 2 was carried out, while the configuration of fiber ropes is illustrated in Table 3.

Table 1: Humidity Content of Flax and Sisal (Libeccio Test)

Test	Standard specifications	Sample		Note
		Flax	Sisal	
Humidity content %	2.50	7.1	7.8	Temperature 20°C Relative humidity 65%

Table 2: Breaking Strength for Sisal and Flax Fibers

Density (At 25 °C)	1.32 ±0.02 kg /1
Mixing ratio (a:b) by weight	2:1
Pot life (at 25 °C)	2 hours
Initial setting time (at 25 °C)	3 - 4 hours
Final setting time (at 25 °C)	24 hours
Full hardness (at 25 °C)	7 days
Min application temperature	15°C
Compressive strength	≥ 400 kg / cm^2
Heat resistance	Up to 250°C

Fig. 1 Pressley Tester - Code 231 A [13]

Table 3: Configuration of Fiber Ropes

Rope structure		3 - strand laid (twisted)
Number of ends / strand		10
Liner density in air (kg/m) load (KN)	Flax	0.112
	Sisal	0.10
Breaking strength (MPa)		50 turns / meter

Kimaboxy 150F which strengthen fiber ropes, was used in processing fibers. They were rubbed with kimaboxy 150F.Thus, ropes were tied from both sides to get dry and to avoid any bending, and then ropes became intransigent, hard, and strong in addition to its resistance to bacteria and moldiness. Table 4 shows features of rubbing kimaboxy 150F. Ropes became dry and intransigent after 24 hours, but final intransigence occurs after seven days, where ropes were extremely strong and intransigent.

Table 4: Technical Data for Kemapoxy 150F

Density (At 25 °C)	1.32 ±0.02 kg /1
Mixing ratio (a:b) by weight	2:1
Pot life (at 25 °C)	2 hours
Initial setting time (at 25 °C)	3 - 4 hours
Final setting time (at 25 °C)	24 hours
Full hardness (at 25 °C)	7 days
Min application temperature	15°C
Compressive strength	≥ 400 kg / cm^2
Heat resistance	Up to 250°C

B. Concrete mixture

One cubic meter of concrete contains 350 kg cement, and the water-cement ratio was 0.45, superplasticizers reaching 0.8% of the cement content was added for maintaining the slump in the range (100-120 mm), 1288 kg coarse aggregate and 644 kg sand. Three cubes 15x15x15 cm3were prepared to calculate the average compressive strength. The standard cubes compressive strength after 28 days was 35 MPa. All tested beams 250x300x2000 mm were cast by the same concrete mixture and kept at room temperature for 28 days. During this period, the beams were covered with a permanent wet covering sheet. In addition, 9 cylinders with dimensions of 150x300 mm that reinforced with sisal or flax were prepared for the pull-out test. Each result was the average of 3

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specimens for each test.

V.TEST RIG AND METHODOLOGY

A. Flexural test

Specimens were loaded at mid-span, using static loading over 1800 mm simply supported span, to examine the flexural behavior of different beams reinforced with different percentages of fiber ropes as a partial replacement of steel bars. The control beam was reinforced with eight 12 mm diameter steel bars, whereas the other beams reinforced with a various replacement ratio of fiber ropes, but with the same diameter of steel bars (12 mm), as shown in Fig. (2).

The mid-span load was adapted by a load cell under displacement control. The figure shows also the structure of the test specimen. The static load was gradually applied by a universal testing machine until failure. The deflection of the beam was recorded at mid-span under the mid-span acting load, using one midpoint Linear Variable Distance Transducer (LVDT) with 0.01 mm accuracy.

The initial load was shown and set apart for every tested beam. On the other hand, crack patterns were set apart on each crack that appeared on the specimen surface, as they spread during loading, starting from cracking load till failure.

B. Pullout Test

Nine concrete cylinders (3 specimens for each test) were prepared. In each cylinder, sisal ropes, flax ropes or steel bars were centered and inserted inside the concrete cylinders. The cylinders dimensions were (150x300 mm2) with 10 cm

VI. EXPERIMENTAL AND THEORETICAL CALCULATIONS

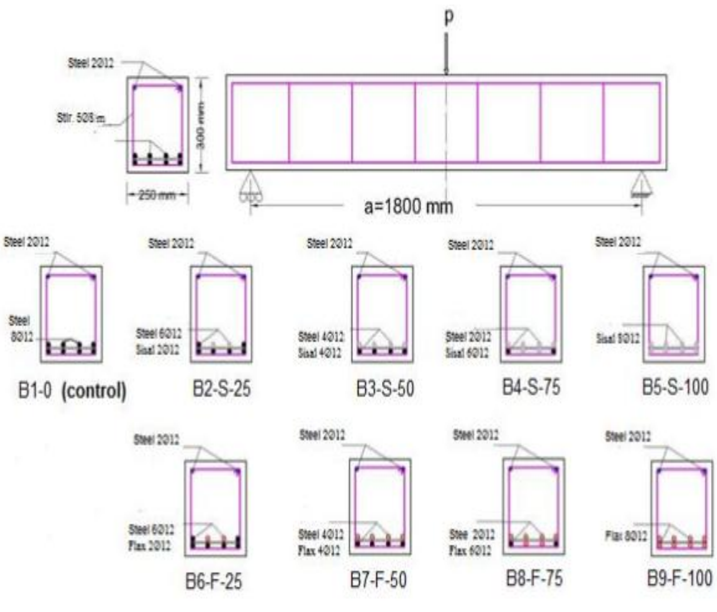

Fig. 2 Details of tested beams

Fig. (2) Shows variation of fiber rope percentages for a Nine beams of dimensions 250x300x2000 mm were prepared with a clear span of 1800 mm to match the flexural strength external part fixed to the universal machine according to Egyptian Standard Specifications [14]. Fig. (3) Illustrates the fiber rope pull out test, before and after the test.

Fig. 3 Bond Failure after Test

C. Tensile strength (sisal and flax ropes)

Samples were trimmed on the universal testing machine. The samples had been firmly fixed on the machine to avoid any slipping. As a result of the ropes ductility and slipping, detection of the rope breaking load can be estimated by Pressley test according to [15]. Accordingly, H.A. McKenna and R. Senthil Kumar [16, 17], estimated the breaking force according to Eq. 1:

Rope break load = RLD x FT x SCE (1)

While the rope break load is in MN,

RLD, Rope linear density and fiber tenacity are in Kg/m,

FT, Fiber tenacity (N/tex)

SCE, strength conversion efficiency is a dimensionless fraction. Table (2) shows that the breaking forces for 12 mm flax and sisal ropes were 25.4 KN and 20.16 KN, respectively.

specimens recommended [14]. The cracking moment Mcr of tested beams may be computed as Eq. 2:

$$M_{cr}= f_r\, I_g/y_t \quad (2)$$

Where yt was the distance from the neutral axis to the tension face of the beam, fr was the modulus of rupture of concrete (5.2 MPa), and Ig was the second moment of inertia of the cross section around the neutral axis. The first cracking load Pcr was then calculated from the cracking moment according to the code provision [18]

The ultimate moment capacity of the beam was calculated using equivalent rectangular stress block of the beam cross section, and then the failure load was calculated. The total compressive loads were equal to the total tensile loads, as shown in Eq. 3. Taking moment at the centroid of tension steel, Ast (Fig. 4) and the ultimate bending moment was expressed by the Eq. 3 [19]:

$$C_c+C_s= T_{s+f} \quad (3)$$

Where Cc= compression force of concrete block

C_s= compression steel force

T_{s+f}= tensile force for steel and fiber ropes

Getting (a), then taking moment around the centroid of tension steel, as shown in Eq. 4

$$Mu = 2/3\,(F_{cu} / \gamma_c)*a*b*(d-a/2)+(d-d'')\,(F_{sc}*A_{sc})/ \gamma_{sc} \quad (4)$$

Where, F_{cu}= concrete compressive strength (35 MPa)

γ_c= allowable strength factor of concrete=1.5

a= height of concrete block in compression zone

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b= cross section wide (250 mm)

d = depth of cross section (from top to centroid of tension bars) = 258 mm

d" = distance from top to centroid of compression steel = 31 mm

F_{sc}= strength of compression steel

A_{sc}= area of compression steel = 113 mm2

γ_{sc}= allowable strength factor of steel = 1.15

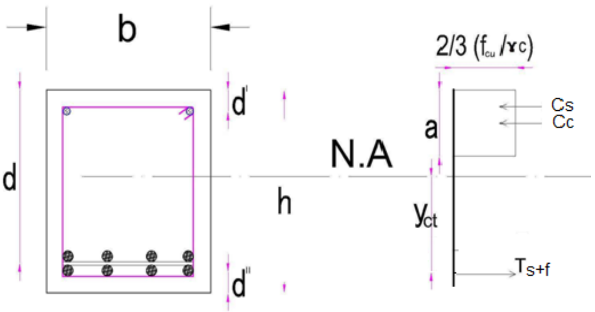

Fig. 4 Acting Forces on the Cross Section Area of Tested Beam

Table 5 indicates the experimental results and theoretical calculations of cracking and ultimate loads for all tested beams. The ratio of the experimental to the theoretical ultimate load for the control beam B1-0 is 1.07. However, it was 2.5 for cracking load. On the other hand, the experimental to the theoretical load ratio for both cracking and ultimate load decreased with increasing fiber rope ratio.

For sisal fiber rope, the ratio of the experimental to the theoretical cracking loads were (1.89, 1.59, 1.33 and 0.70) for the fiber rope percentages (25%, 50%, 75% and 100%), respectively. However, the experimental to the theoretical ultimate loads were (1.01, 0.97%, 1.01%, and 0.91%), respectively. On the other hand, for flax fiber rope, the experimental to theoretical cracking loads were (2.23, 1.87, 1.52 and 0.89) for fiber rope percentages (25%, 50%, 75%, and 100%), respectively. The experimental to theoretical ultimate loads were (1.01, 0.94%, 0.93% and 0.79%), respectively.

It was noticed that the ratio of the experimental to the theoretical loads for both sisal and flax fiber ropes decreased when fiber rope percentage increased for both cracking and ultimate loads. This was due to the lower tensile strength of the fiber ropes compared to that of steel bars. Steel bars and fiber ropes acted together until fiber ropes broke. Consequently, tensile steel bars will act alone and the experimental values will be reduced. However, the experimental to theoretical loads ratio for beams reinforced with flax ropes was higher than those reinforced with sisal ropes, because the breaking load of flax was larger than sisal. For full replacement of steel bars by fiber ropes, the experimental to the theoretical load factors were reduced. This would be due to the shifting of ropes positions or the changing the physical properties of the ropes inside the concrete. Therefore, the physical and mechanical properties of ropes inside concrete should be studied further.

Table 5 Experimental and theoretical cracking and ultimate loads

Beam No.	Experimental (E)		Theoretical (T)		$(P_{cr})_{Exp.}/(P_{cr})_{Th.}$	$(P_u)_{Exp.}/(P_u)_{Th}$
	P_{cr}	P_u	P_{cr}	P_u		
B1--0	86.87	155.12	34.76	144.5	2.50	1.07
B2-S-25	67.69	129.74	35.74	128	1.89	1.01
B3-S-50	57.54	107.17	36.9	110.7	1.56	0.97
B4-S-75	50.77	93.64	38.2	92.8	1.33	1.01
B5-S-100	28.20	67.69	39.8	74.21	0.71	0.91
B6-F-25	78.97	133.12	35.48	132.2	2.23	1.01
B7-F-50	67.69	112.82	36.27	119.65	1.87	0.94
B8-F-75	56.41	99.28	37.16	106.6	1.52	0.93
B9-F-100	33.84	73.33	38.17	93.17	0.89	0.79

VII. RESULTS AND DISCUSSION

This research aimed at reducing the cost of reinforced concrete buildings, especially in developing countries. Utilization of fiber ropes instead of steel reinforcement reduces the cost. Consequently, the behavior of flexural members incorporating both steel and fiber ropes and those containing fiber ropes only in reinforced concrete structures should be investigated. The following indicators in Eqs (5-7) are used in the analysis of tested beams:

$$DCF = (\Delta_u - \Delta_{cr}) / \Delta_u \quad (5)$$

$$LCF = (Pu - Pcr) / P_u \quad (6)$$

$$SF = \Delta_s / \Delta_u \quad (7)$$

Where LCF = Load capacity factor, DCF=Deformation capacity factor,

SF = Serviceability factor, P_u=Ultimate load,

P_{cr}=Cracking load, Δ_u=Deflection at ultimate load,

Δcr= deflection at cracking load, Δs=Serviceability deflection (span of beam/250).

A. Effect of Fiber Ropes Percentage on the Behavior of Beams

Figures (5-8) represent the load-deflection relationships of beams incorporating sisal or flax ropes as a partial percentage of control beam steel. In general, beams with sisal ropes showed larger deflections and lower ultimate loads than beams reinforced with flax. However, beams reinforced with sisal or flax showed larger deflections and lower ultimate load in comparison with the control beam. On the other hand, the break strength of sisal is lower than flax ropes. Hence, the ultimate load of beams with sisal ropes were lower than that of beams reinforced with flax ropes at the same fiber rope percentage.

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1. Beams Reinforced with (25% Fiber Ropes + 75% Steel Bars)

Fig. (5) Shows the load vs. deflection of beams reinforced with fiber ropes (25% of total reinforcement of the cross section) and which reinforced with steel bars (75% of the total reinforcement) that named control. The failure load of the beams incorporating sisal and flax ropes represented about 84 and 86% of the failure load of the control beam, respectively. During loading until failure, the deflection of beams with fiber ropes was larger than that of the control beam at the same applied load. On the other hand, the beams with fiber ropes exhibited approximately the same deflection as beams fully reinforced with steel bars. The ultimate load of the beam with flax ropes was about 3% higher than that with sisal ropes and exhibited about4% larger deflection than the beam with sisal ropes.

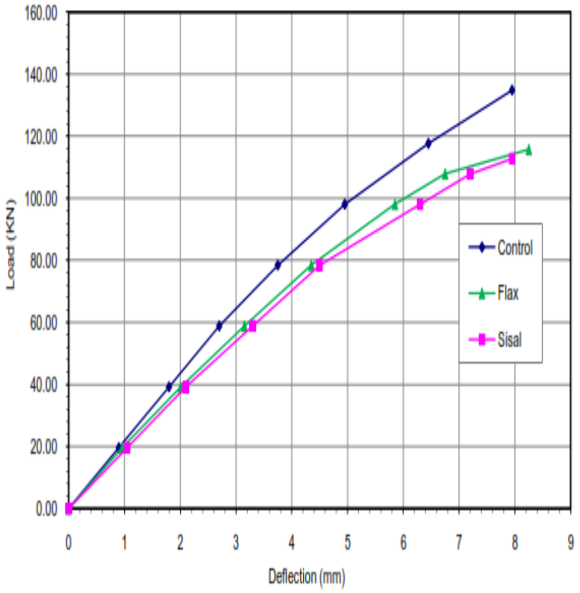

Fig. 5 Load-deflection relationship of beams reinforced with (75% steel +25% fiber rope)

2. Beams Reinforced with (50% Fiber Ropes + 50% Steel Bars)

Load-deflection relationships of beams reinforced with (50% fiber ropes + 50% steel bars) were compared with those of the control beam (reinforced with 100% steel bars), as shown in Fig. (6). It was observed that the failure load of the beams with sisal and flax ropes was 69% and 73% of that of the control beam, respectively. However, the deflection of beams with fiber ropes was greater than that of the control beam. On the other hand, beams with flax and sisal ropes exhibited about 20% and 13% increase in their deflections, respectively, if compared to the control beams at failure. Moreover, beams with sisal rope showed larger deflections than the beam with flax ropes. Utilizing (50% fiber ropes + 50% steel bars) increased the deflection of beams with sisal ropes those with flax ropes by about 7%, whereas the ultimate load of beams with flax ropes was higher those with sisal ropes by about 5%.

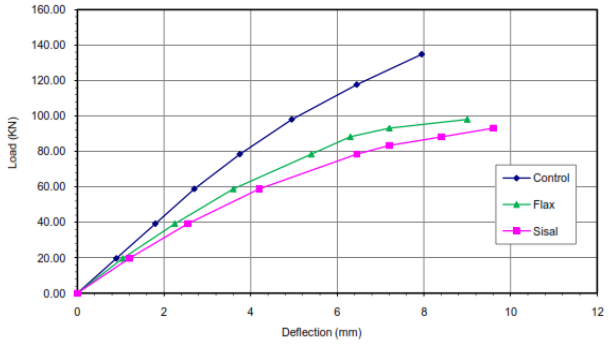

Fig. 6 Load-deflection relationship of beams reinforced with (50% steel +50% fiber rope)

3. Beams Reinforced with (75% Fiber Ropes + 25% Steel Bars)

Load-deflection relationships of beams with (75% fiber ropes + 25%% steel bars) as well as those of a control beam were shown in Fig. (7). The failure loads of the beams reinforced with sisal and flax ropes were 60% and 64%, respectively, of the failure load of the control beam. However, the deflection of beams with fiber ropes was larger than that of the control beam at the same applied load until failure. In this respect, the beams with flax and sisal ropes at failure, exhibit deflections larger by about 32% and 50%, respectively, compared to the control beam. Beams with sisal ropes showed more deflection than beams with flax ropes. Beams with sisal ropes showed more deflection compared to beams with flax ropes (about 14%), whereas its ultimate load was lower by about 6%.

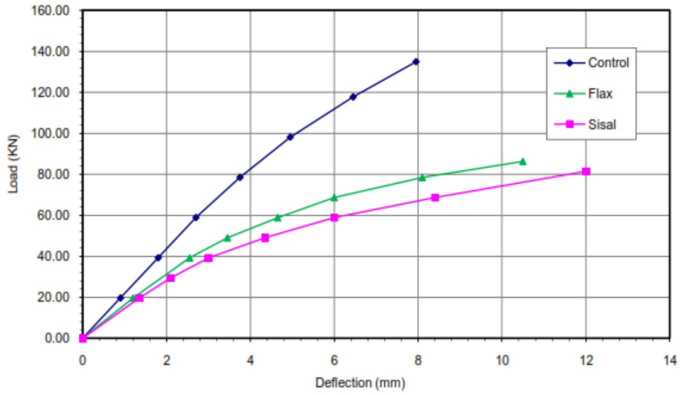

Fig. 7 Load-deflection relationship of beams reinforced with (25% steel +75% fiber rope)

4. Beams Reinforced with (100% Fiber Ropes)

The load-deflection relationships of fully fiber reinforced beams (100% fiber ropes) are shown in Fig. (8). The failure load of the beams reinforced with fully sisal and flax ropes decreased to 44% and 47% of that of the control beam, respectively, whereas the deflections of beams with up to 75% fiber ropes showed larger deflections than the control beam at the same acting load during gradually loading until failure. At failure, the beams with flax and sisal ropes showed higher deflections of about 108% and 126% of that of the control

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beams, respectively. Beams with sisal ropes showed larger deflections than beams with flax ropes. The deflections of beams with sisal ropes were 18% larger than of those with sisal ropes. However, its ultimate loads are 8% less than those of beams with flax ropes.

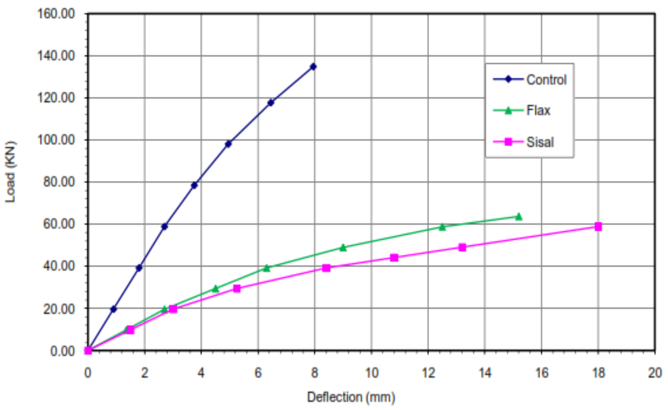

Fig. 8 Load-deflection relationship of beams reinforced with (0% steel +100% fiber rope)

B. Investigation of Beams with Fiber Ropes

Figures (9 and 10) show the load-deflection relationships for all percentages of sisal fiber ropes and the crack patterns of beams after testing. For both sisal and flax ropes, the increasing the percentage of fiber ropes decreased the failure load and increases the deflections. Moreover, beams with sisal ropes showed more cracks than beams with flax. Utilization of up to 50% fiber ropes of the total reinforcement led to more cracks and close spaces between cracks if compared with the control beam. This could be due to the interaction between fiber ropes and steel bars during loading, especially when using 50% fiber robes and 50% steel bars.

1. Beams with various percentages of sisal ropes

Fig. (9) shows the load-deflection relationships of beams reinforced with various percentages of sisal ropes. The deflections for all sisal ropes percentages were larger than those of the control beam at the same acting load. The ultimate load decreased with increasing sisal ropes percentage. For 25% sisal ropes, the ultimate load was ~ 84% of the ultimate load of control beam. However, the deflection was the same as that of the control beam. For beams with more than 25% sisal ropes (50%, 75% and 100%); the ultimate load decreased to about 70%, 60% and 44% of the ultimate load of the control beam, respectively, while their deflections increased at failure load, especially for beams with more than 50% sisal ropes. Cracks pattern of the beams with sisal ropes was denser, crack width was smaller, and distances between cracks were narrower, especially in beams containing up to 50% sisal ropes.

2. Beams with Different Percentage of Flax Ropes

Fig. (10) represented the load-deflection relationships of all beams with different percentages of flax ropes. All flax ropes showed the same trend as sisal ropes. For 25% flax ropes, the ultimate load was 86% of that of the control beam. Whereas, for beams with more than 25% flax ropes (50%, 75% and 100%), the ultimate strengths were 73%, 64% and 47% of the control beam ultimate load, respectively. However, deflections at failure were higher for all beams with flax ropes compared to that of the control beam, but less than the corresponding beams with sisal ropes. The crack pattern of 25% flax ropes shown in Fig. (10) was similar to that of the control beam. However, for beams with 50% flax ropes, the cracks number and their width increased if compared with the crack pattern of the control beam.

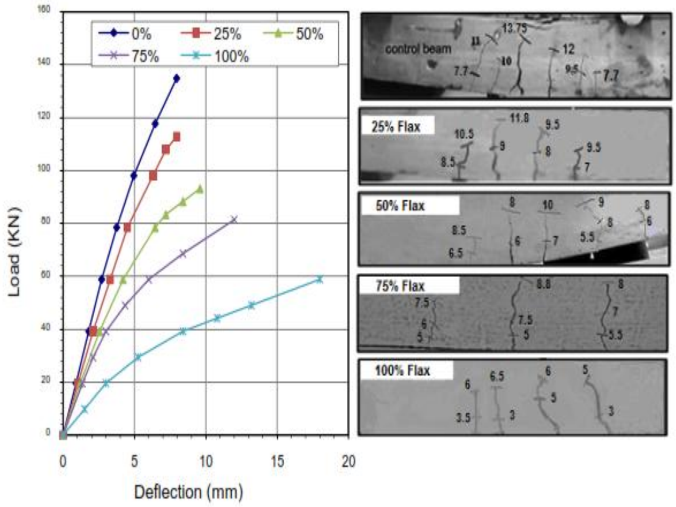

Fig. 9 Load-deflection of beams reinforced with flax bars and cracking pattern for tested beams

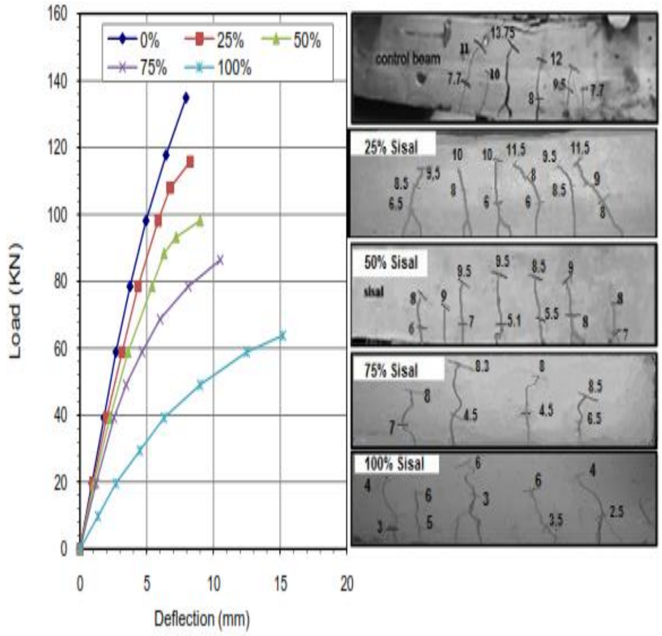

Fig. 10 Load-deflection of beams reinforced with sisal bars and cracking pattern for tested beams

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C. *Cracking and ultimate loads*

Fig. (11) shows both cracking and ultimate loads for all tested beams. The initial cracking loads of beams reinforced with fiber ropes decreased when fiber ropes percentage increased, whereas the ultimate loads of beams with fiber ropes decreased when the fiber ropes percent increased. The beams reinforced with 25%, 50%, 75% and 100% sisal ropes exhibited cracking loads of 78%, 66%, 58% and 32% of the cracking load of control beam, respectively. On the other hand, the cracking loads of beams incorporating flax ropes were 91%, 78%, 65%, and 39% of the cracking loads of the control beams, respectively. Moreover, the failure loads of beams reinforced with 25%, 50%, 75% and 100% sisal ropes were 54%, 54%, 54% and 51%, respectively. The corresponding values for beams reinforced with flax ropes were 61%, 62%, 65% and 48%, respectively. The initial cracking load to ultimate load of the control beam recorded 56%. The initial to failure loads of beams reinforced with flax ropes were higher than those of beams with sisal ropes at the same fiber rope percentage. This could be due to the high initial cracking load of the beams with flax ropes compared to those with sisal ropes and the narrow differences of the ultimate loads for beams, containing sisal or flax ropes.

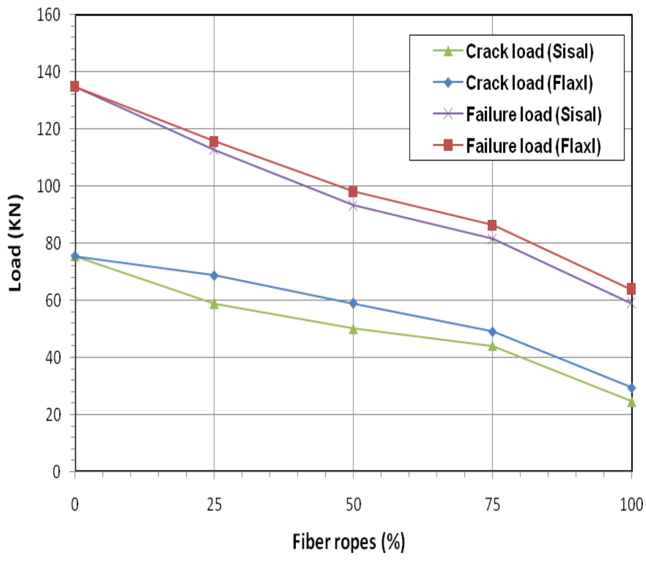

Fig. 11 Cracking and failure loads of tested beams

D. *Deformation capacity factor (DCF)*

The deformation capacity factor (DCF) represented in Equation (5) represents the ductility of tested beam. DCF values for all beams reinforced with fiber ropes were more than that of the control beam. Increasing fiber ropes percentages increased the DCF factors, as shown in Fig. (12). DCF of control beam records 0.55, whereas for beams reinforced with sisal ropes 25%, 50%, 75% and 100% it is 0.58%, 0.64%, 70% and 78%, respectively. However, DCF of beams reinforced with flax ropes percentages was 0.55%, 0.60%, 0.67% and 71%, respectively. In general, DCF values of beams utilizing fiber ropes especially sisal ropes were higher. This would be due to the features and behavior of fiber ropes that extended till breaking the load.

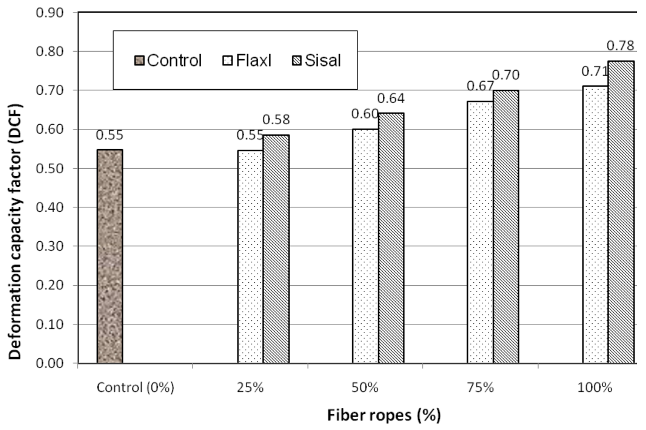

Fig. 12 Deformation Capacity Factor (DCF) of tested beams

E. *Load capacity factor (LCF)*

The beam load capacity factor (LCF) when gradually loaded from initial cracking to failure cracking was represented by Equation (6). LCF of the control beam was 0.44, while it was in the range (0.4% - 0.43%) for beams with up to 75% sisal ropes. It was also in the range (0.45%-0.48%) for beams with up to 75% flax ropes. This means that, LCF of beams with flax ropes was slightly more than LCF of the control beam or the beams with sisal ropes. For full reinforcement with fiber ropes LCF was increased, as shown in Fig. (13). LCF is 0.54 and 0.58 for beams with 100% sisal and flax ropes, respectively. This could be due to the low cracking loads of the beams compared to their failure loads.

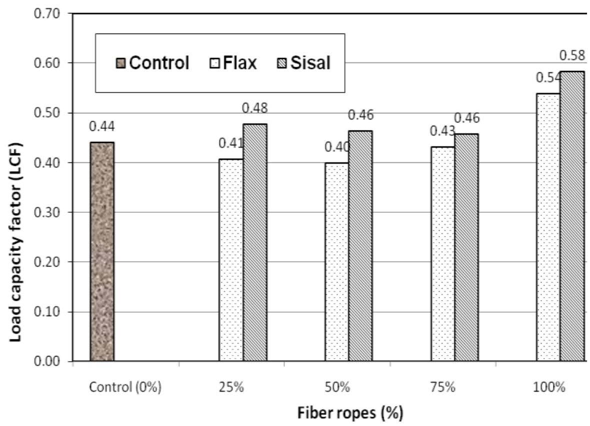

Fig. 13 Load Capacity Factor (LCF) of Tested Beams

F. *Serviceability load factor (SLF)*

Serviceability load (Ps) indicates the limit state of the applied load, which causes deformation L/250, where L is the clear span of the beam. Serviceability load factor (SLF) used in present work is the serviceability load (Ps) divided by the

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ultimate load (Pu). The term SLF indicates the beam limit to withstand the service load compared to the ultimate load, as represented by Equation (7). All beams reinforced with up to 50% fiber ropes indicated values of SLF narrow to the control beam. SLF of the control beam was 0.96, whereas SLF of beams with up to 50% fiber ropes was in the range (0.91-0.97), as shown in Fig. (14). Beams reinforced with 75% fiber ropes recorded 0.8 and 0.88 for sisal and flax ropes, respectively. Beams that reinforced with full sisal or flax fiber ropes showed SLF values of 0.6 and 0.69, respectively. SLF values of beams containing more than 50% sisal ropes were declined because of their high deflection values, which exhibited small serviceability load at deflection value (L/250).

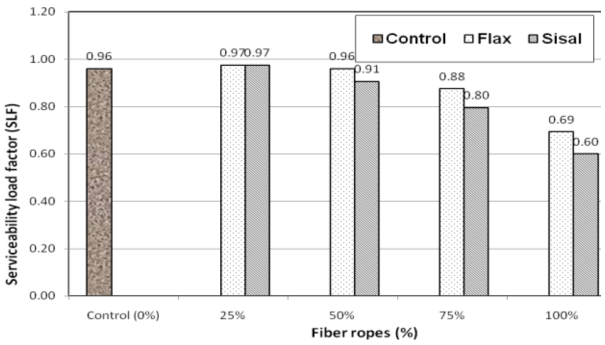

Fig. 14 Serviceability Load Factor (SLF)

VIII. PULLOUT TEST RESULTS

The pull out test results indicate that fiber ropes are cut before pull out, as indicated in Table 6 and Fig. (3) that means the pull out strength of fiber ropes were higher than the breaking strength (1.78 and 2.24 MPa for sisal and flax ropes, respectively), whereas the pull out test of steel bar recorded 5.9 MPa.

Table 6 Bond strength test results

Type	Pull out load (KN)	Bond strength (MPa)	Mode of failure
Steel	67	5.93	Slipping
Sisal	20.16	>1.78	Rope breaking
Flax	25.4	>2.25	Rope breaking

IX. CONCLUSIONS

The performance of concrete elements in bond and flexural tests with sisal and flax ropes as a partial replacement of steel bars can be summarized as follows **:**

1) Replacing 25% of the steel reinforcement of a concrete beam by fiber ropes, about 85% of the failure load and similar deflection of the control beam can be obtained. Increasing the replacement to 50% decreased the failure load to 71% and increased the deflection by about 16% than that of the control beam. Further increase of the replacement to 75% decreased the failure load to 62% of that of the control beam, and the deflection recorded further increase to about 41%. Furthermore, replacing all steel reinforcement by fiber ropes led to about 45% of the failure load of the control beam, and to about 117% increase in its deflection values.
2) Beams reinforced with flax ropes showed slightly more failure loads than others reinforced with sisal ropes. However, flax ropes beams exhibited lower deflections than sisal beams.
3) With the increase of fiber ropes percentage especially in beams with sisal ropes, initial cracking loads of beams appeared earlier than that of the control beam, and the deformation capacity factors (DCF), which represents ductility also increased.
4) Load capacity factor (LCF) of the beams was obviously enhanced for fiber ropes substitution more than 75%.
5) Beams reinforced with up to 50% fiber ropes showed serviceability load factor (SLF) values closer to those of the control beams. However, enhancement of SLF was observed for beams with more than 50% fiber ropes.
6) Increasing fiber rope percentage reduced the experimental to theoretical cracking load and ultimate load of the beam.

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