An Experimental Investigation into the Mechanical Properties of New Natural Fiber Reinforced Mortar

Dr. Sinan Abdulkhaleq Yaseen
Engineering College, University of Salahaddin / Erbil
Email: sinan_abd@yahoo.com

Received on: 19/7/2012 & Accepted on: 31/1/2013

ABSTRACT

Since the starting the 21st century, there is an increased awareness that non-renewable resources are becoming scarce, and dependence on renewable resources is growing. The 21st century may be the cellulosic century as we look more and more to renewable plant resources for products. It is easy to say that natural fibers are renewable and sustainable. Although the use of these materials is not new, horse hair was used in mortar and straw for mud bricks, and many plants types like sisal, coir, bamboo, jute, akwara, elephant grass…etc. In this papers, a human hair fibers (HHF) is studied as a reinforced material in cementitious material. A total of 86 concrete specimens (Cubes, cylinders, prisms and plates) are tested to study the effect of including human hair fibers HHF reinforcement on the mechanical properties of flowable mortar fiber reinforced concrete. Fibers of different lengths and equivalent diameters were used with an aspect ratio ranged from 500 to 700, fiber content ranges from zero to 1 percent by volume. The influence of fiber content on the compressive strength, splitting tensile strength, flexural strength and load deflection is presented for two w/c ratios (0.6 and 0.7). An improvement in the energy absorption capacity due to the fiber addition is observed, and the optimum fiber volume fracture is seen to be 0.8%. The experimental findings in our tested samples will encourage future researches in this direction for long term performance to extending this cheap type of fibers for use in structural applications especially for low strength cementitious materials.

Keywords: Natural Fiber Reinforcement, Human Hair Fiber HHF, Splitting Tensile Strength, Compressive Strength And Flexural Strength.

دراسة الخواص الميكانيكية لمونة السمنت المسلحة بنوع جديد من الالياف الطبيعية

الخلاصة

منذ بداية القرن ٢١ ازدادت الوعي بان المصادر المتجددة اصبحت نادرة. فنمت الاعتماد على المصادر المتجددة , ويمكن تسمية قرن ٢١ بالقرن السليلوزي عند النظر الى منتجات المصادر النباتية. فيمكن القول بان الالياف الطبيعية هي هي مصادر متجددة ومستمرة. بالرغم من ان هذا المواد لا يعتبر جديدة, فشعر الحصان استعمل في المونة واستعمل القش في صناعة الطابوق الطيني, كما واستعمل الالياف النباتية الطبيعية كنبات السيزال, الليف الهندي, الخيزران,

https://doi.org/10.30684/etj.31.10A5
2412-0758/University of Technology-Iraq, Baghdad, Iraq

نبات الجوت وغيرها.في هذا لبحث, لقد تم فحص ٨٦ نموذجا (مكعبات, اسطوانات,الموشور ,مع الصفائح الرقيقة) لدراسة تأثير اضافة الياف شعر الانسان كتسليح على الصفات الميكانيكية للكونكريت المسيل المسلح بألياف الشعر. لقد تم استعمال الياف ذات اطوال مختلفة و بمعدل قطر معين للحصول على حدود نسبةالنحافه يساوي ٥٠٠-٧٠٠.وتم دراسة التأثير الليفي على مقاومة الضغط,السحب و مقاومة الانحناء وكذلك دراسة منحنيات الحمل-الانحراف لنسب مختلفة من الماء\السمنت (٠,٦ و٠,٧). اضافة الليف بالنسبة الحجمية ٠,٨% ادى الى زيادة مقاومة كل من الضغط, السحب والانحناء وكانت ٠,٨% الحالة المثالية جدا لهذا التطور. مستجدات البحث سوف يؤدي الى زيادة الابحاث في مجال هذا النوع الرخيص من الالياف. ان اضافة الالياف اظهر كفاءته في زيادة مقاومة النماذج في الانواع السمنت ذات المقاومة القليلة

INTRODUCTION

Since the advent of fiber reinforcing of concrete in the 1940`s[1], a great deal of testing has been conducted on the various fibrous materials to determine the actual characteristics and advantages for each product. It is designed to give optimal performance characteristics for the given set of materials, usage and exposure conditions, consistent and parallel with the requirements of cost service, life and durability. Many types of fibers were used and tested (asbestos, steel, glass, carbon, synthetics,…etc.)[١,٢]. As natural fibers, horse hair was used in mortar and straw for mud bricks, and many plants types like sisal, coir, bamboo, jute, akwara, elephant grass……etc.[٤,٥], were also used.

There is a relation between concrete strength and its ductility, the higher the strength of concrete, the lower its ductility. This inverse relation between strength and ductility is a serious drawback for the use of high strength concrete. A compromise between these two concrete properties can be obtained by adding discontinuous fibers. The concept of using fibers to improve the characteristics of construction materials is very old. Addition of fibers to concrete makes it more homogeneous and isotropic[٦], and transforms it from a brittle to a more ductile material. When concrete cracks, randomly oriented fibers arrest a micro-cracking mechanism and limit crack propagation, thus improving strength and ductility.

Under loading, reinforced fibers will stretch more than concrete. Therefore, the composite system of fiber reinforced concrete is assumed to work as if it is unreinforced until it reaches ‘first crack strength’. From this point fiber reinforcing takes over and holds the concrete together.

Fibers are usually used in concrete to control plastic shrinkage cracking and dry shrinkage cracking. They also lower the permeability of concrete, thus reduce the bleeding of water. Some types of fibers reduce greater impact, abrasions and shatter resistances in concrete [٧].

For fiber reinforcing, maximum load carrying capacity is controlled by fibers pulling out of the composite, because fiber reinforcing does not have a deformed surface like larger steel reinforcing bars. This condition limits performance to a point far less than the yield strength of the fiber itself. This is important because some fibers are more ‘slippery’ than the others when used as reinforcing and will affect the toughness of the concrete product in which they are placed (toughness is based on the total energy absorbed prior to complete failure)[٨و٩و١٠و١١].

The main purpose of this paper is to study the mechanical properties of HHFRC materials. An experimental program has been carried out to use human hair fibers

HHF as a natural fiber in the applications of the fiber concrete. One of the indications for the application of HHF reinforcement in this field was a lack of adequate information regarding the compressive strength, splitting tensile strength, flexural strength, load-deflection response, and ductility of the samples. An attempt was made to investigate the strength and behaviour of mortar-fiber mixture. This has been prompted by an abundance of relatively cheap source of fibers, subsequently, the need to import foreign reserve expenditure of other fibers reduced. It is seen that HHF can be used to control cracks and deflection[1].

EXPERIMENTAL WORKS

Material

Fiber reinforced mortar has been produced using certain proportions of HHF, fine aggregate and paste. The paste consists of cement, water and superplasticizer. Table 1 shows mortar mix proportion used in the testing program. The mix proportion was 1:3 (Cement: Sand). Type 1 Ordinary Portland Cement and natural sand passing sieve 2.36mm were used Table 2. superplasticizer was used for each mix Table3. Two w/c ratios of (0.6 and 0.7) were used.

Superplasticiser (GLENIUM ACE 30) is an admixture of a new generation based on second -generation polycarboxylic ether polymer with high early strength gains. GLENIUM ACE 30 is free of chloride & low alkali Table 3. It is compatible with all types of cements.Its suitable for making precast concrete elements at all workability's including Rheoplastic or Super workable concrete having fluid consistence, no segregation, a low water binder ratio and, consequently high early.

A quantity of human hair was collected and added to a mortar mixture. This amount was measured as a percentage of the total volume of the composite (mortar and fiber) and it is termed as volume fraction V_f. Orientation of the fibers is generally random and simple because they are not placed at a time in a single direction.

The average nominal length (l) and diameter (d) of HHF was found to be 25mm and 0.03 mm respectively, fiber lengths and diameters determine the aspect ratio (l/d). An equivalent diameter for the calculation of the aspect ratio for the fibers was used. The increase in the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. Fibers which are too long tend to 'ball' in the mix and create workability problems. Therefore, an equivalent aspect ratio of about 500-700 was found to be ideal for this procedure by making a trial mixes to find the percentage ratio ranges that can be test, and study with more observation about the aspect ratio in several references [1,٦]. The variations in diameter and length were $\pm$ 0.005mm and $\pm$ 5mm respectively.

The ultimate strength of fibers was evaluated by clipping the two ends of the fiber leaving at least 150mm length in the middle. Then one end of the fiber was fixed by winding it around a pulley and the other end was bound around a hook. The fiber was loaded to fail by increasing the weight on the hook. Failure occurred by rupture of the fiber giving an ultimate strength of about 1100 MPa.

Preparation of Spacemens

Two mixes of different water to cement ratio (0.6 and 0.7), and three volume fractions of fiber (0.6 %, 0.8 and 1%) were used for each w/c ratio as shown in Table(1). In order to maintain uniform workability, the superplasticiser dosage was adjusted in the mix. Worth mentioning, the discovery of the extraordinary dispersing action of superplasticiser raises the availability of different fiber types with different properties. Six cubes (size: 70.7mm x 70.7mm x70.7mm) for compression test, three cylinders (size: 100mm diameter x 200mm length) for tensile splitting test, three prisms (size: 70mm x 70mm x 400mm length) for flexural test, and two of one-way plate specimens(size: 20mm x 100mm x 350mm) for load deflection test; were used for each w/c ratio and volume fraction of fiber.

The V_f of fibers in these tests were limited to 1% of volume fraction because further increase of the fibers led to balling and resulted in non-workable mortar.

Table (1)The mix proportions.

Mortar Mix Properties		
Material	Weight Kg/m³	
	W/C = 0.6	W/C = 0.7
Cement	473.00	451.00
Sand	1419.00	1353.00
Water	269.80	299.91
Superplasticiser	14.20	15.79
Cement/Sand	1:3	1:3

Required quantities of cement and sand were mixed thoroughly in a drum type mixing machine. Fibers were added to the mortar in three ways; a) to dry mixture of cement and sand, b) to wet mixture of cement and sand (mortar) c) mixed with superplasticier and added to wet mortar. The best method was the first method because the bundles were separated by a fine granular of cement and sand while the use of wetting method in the second method or mixed with superplasticier in the third method made a new bundles instead of separating them. Mixing was continued till a uniform matrix was obtained. The mixture was properly placed in the moulds and well vibrated. After 24 hrs the one way-plates and the control specimens were demoulded and cured for 7 and 28 days, then tested under a compression machine by using a special apparatus Figure (1).

The workability of freshly mixed concrete is a measure of its ability to be mixed, handled, transported, and, most importantly, placed and consolidated with a minimal loss of homogeneity and minimal entrapped air. The slump test was used to control the test, but it may not be a good indicator of workability for FRC. However, once it has been established that a particular FRC mixture has satisfactory handling and placing characteristics at a given slump, the slump test may be used as a quality control test to monitor the FRC consistency from batch to batch[1٦]. The enhancement was observed in the mixes for low fiber percentage more than that for high percentages. These results confirmed before [1] [٦], but not readings were recorded because of the variety of the data caused by adherence of the mortar reinforced by the fibre with the cone.

Table (2)Sieve analysis.

Sieve size	Percent passing by weight	Percent passing ASTM C-33
No. 8 (2.36 mm)	90	80-100
No. 16 (1.18 mm)	72	50-85
No. 30 (0.60 mm)	50	25-60
No. 50 (0.30 mm)	27	10-30
No.100 (0.15 mm)	5	2-10

Table (3) superplasticiser

Aspect	Light brown liquid
Relative Density	1.06 ± 0.01 at 25°C
pH	>6
Chloride ion content	< 0.2%

Figure (1) Tested specimens.

RESULTS AND DISCUSSION

STRENGTH:

The strengths with respect to fiber volume fraction

The unit weight of HHF reinforced mortar is not dependent on the percentage of fiber content. Increase in fiber percentage slightly reduces the unit weight of mortar, the consistency of the mix was appropriate for up to 0.8 % fiber content. The optimal volumetric fiber content was between 0.6 to 0.8% as shown in the test results. Average values of test results of specimens for each percentage of fibers are given in Table (4).

The relationship between compressive, tensile splitting and flexural strengths of HHF reinforced mortar and fiber percentage is presented in figures (2,3) and (4). Maximum compressive, tensile splitting and flexural strength values for all of the w/c`s reached when the volumetric fraction raised to o.8% at 7th days curing.

Table (4) The average testing results for all the specimens.

		7 Day			28 Day		
W/C	Vf	Compression (Mpa)	Tensile Splitting (Mpa)	Flexural (MPa)	Compression (MPa)	Tensile Splitting (MPa)	Flexural (MPa)
0.6	0.0%	6.282	0.700	2.653	14.664	0.955	7.459
	0.6%	6.082	0.694	3.752	14.588	1.210	2.836
	0.8%	7.654	0.885	4.232	14.524	1.235	2.402
	1.0%	2.721	0.700	1.235	13.336	1.324	2.105
0.7	0.0%	5.122	0.446	2.150	12.404	1.019	6.406
	0.6%	5.362	0.605	3.432	12.314	1.057	3.980
	0.8%	5.802	0.719	3.111	11.764	1.510	3.683
	1.0%	3.921	0.509	2.150	11.924	1.311	3.913

Compressive strengths: For 7th day curing, it is found that increasing was reported in the results of compressive strength for different fibre percentage except for 1.0% fiber percentage(the fibre bundles cant fibrillated well by treatments because of the high percentage of the fibre which means higher surface area and which contacted with the mortar that produce a weak points in the samples) , while the values of compressive strengths were reduced for 28th day curing, which is justifies that the efficiency of using the HHF in any volume fraction appears in weak mortar. The same result of increasing the strength for different fibre percentage till the optimum fibre percentage was observed in previous papers [12]. Based on the finding concerning the volumetric changes in fibers, the compressive strength results for 7th and 28th day curing specimens are justified.

Compressive strength with respect to w/c and curing time: The relationship between compressive strength of HHF reinforced mortar at 7th and 28th day curing and fiber percentage is presented in figure (2), an increase in the compressive strength founded for the 7th day cured samples for the both w/c 0.6 and 0.7 in Table (5) equals 21.8% and 13.27% respectively, and decreasing was reported in the results of compressive strengths for different w/c ratio for 28th day cured samples, indicating that the efficiency of increasing the compressive strengths occurs for early strength samples and less than that for higher strength samples.

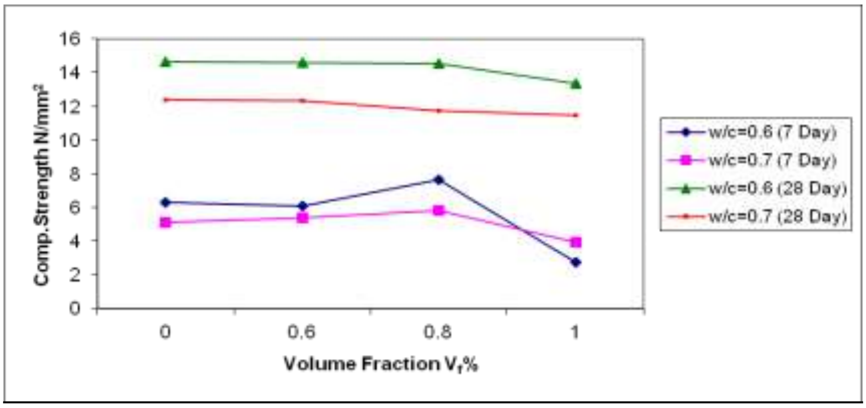

Figure (2) Compressive strength – Volume fraction Relationship.

Tensile splitting strength: After relative drying of reinforced mortar at 7th and 28th day curing, the increasing in fiber volume resulted in pulling-out of fibers at higher load. An increase in the tensile splitting strength found for the 7day cured sampls for both w/c 0.6 and 0.7 in Table 5 equals 18.5% and 27.3% respectively, and for 28th cured samples these values increased to 34.45% and 48.1%respectivelly. Accordingly, the enhancement of tensile splitting strength at 7th and 28th day curing was achieved. So, the ductility obtained was more than expected to minimize the volume change, and provide durable and relatively high bond strength as shown in Figure (3).

Tensile splitting strength with respect to w/c and curing time: The relationship between tensile splitting strength of HHF reinforced mortar at 7th and 28th day curing and fiber percentage is presented in figure (3), a significant improvement is noted in the results equals to 18.5% and 27.3% for w/c 0.6 and 0.7 of 7th day cured samples respectively, and 34.45% and 18.7% for w/c 0.6 and 0.7 of 28th day cured samples respectively Table (5). The strength results show that the development of the strength due to the addition of the fiber has a noticed improvement in the tensile strength for all of the cases.

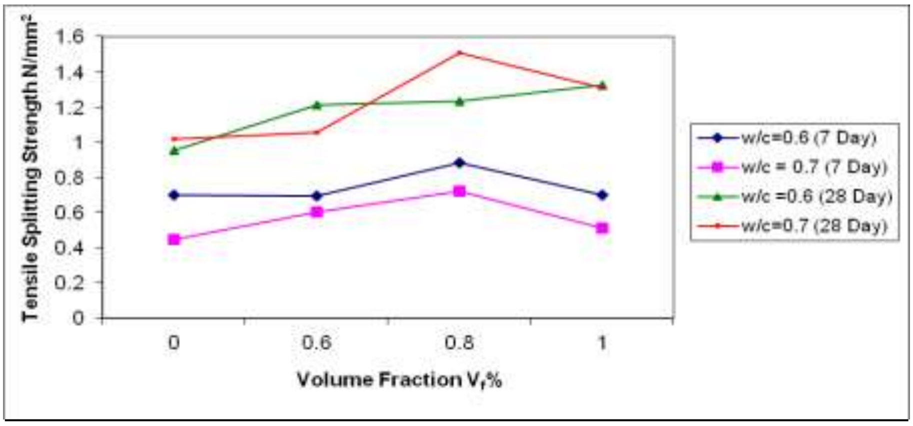

Figure (3) Tensile strength – Volume fraction Relationship.

Flexural strength: A reduction in the flexural strength is observed for all of the values at 28th day curing as shown in figure 4. Three loading tests of samples have shown that human hair fibers were phenomenally effective in increasing the flexural strength and ductility of the specimens at early ages. Whilst for concrete specimens at age of 28 days, the flexural strength has been dropped. This test has proved the ability of human hair fiber to increase flexural capacity of specimens at early ages only. The reason for that might be due to the increase in the strength of concrete with age, which increased the critical volume fraction of fibers required for multiple cracking to be achieved. Therefore a low strength matrix might be useful in the case of human hair fiber reinforcement composite.

Another reason for this case is the absence of the information of the efficiency of durability of human hair fiber in concrete. Therefore, the fiber might be loss it is strength while reaching 28day age .The experimental findings in our tested samples will encourage future researches in this direction for long term performance to extending this cheap type of fibers for use in structural applications

Generally fibres do not increase the flexural strength of concrete, so it can not replace moment resisting or structural steel reinforcement. Some fibres reduce the strength of concrete. Increase in the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix. However, fibres which are too long tend to ball in the mix and create workability problems[17].

Flexural strength respect to w/c and curing time: The relationship between flexural strength of HHF reinforced mortar at 7th and 28th day curing and fiber percentage is presented in figure 4, a significant improvement is noted in the results equals to 59.9% and 59.6% for w/c 0.6 and 0.7 of 7th day cured samples respectively, and a reduction of -163% and -61% for w/c 0.6 and 0.7 of 28th day cured samples respectively Table 5. The results of flexural strength show an increase in strength for all of the w/c ratios of a 7th day curing samples and a decrease in strength for all of the w/c ratio of a 28th day cured samples.

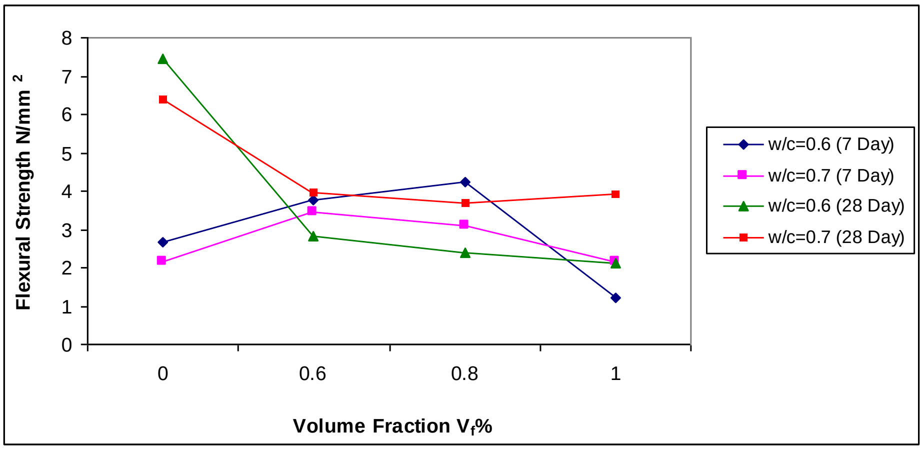

Figure (4) Flexural strength – Volume fraction Relationship.

Table (5) the change ratio in sample strength results for V_f = 0.8% with respect to V_f = 0.0%.

Test	w/c	7day	28 day
Compressive strength	0.6	+21.8%	-1%
	0.7	+13.27%	-5.16%
Tensile Siplitting	0.6	+18.5%	+34.45%
	0.7	+27.3%	+48.11%
Flexural	0.6	+59.5%	-163%
	0.7	+59.6%	-61%

LOAD- DEFLECTION BEHAVIOUR

A third point flexural bending system is adopted for the plates in the load-deflection test. Specimens were tested in a universal testing machine. Figures (5,6) show comparison of load-deflection ($P-\delta$) curve in the flexural specimens with various volumetric fiber content and w/c ratios (0.6 and 0.7) in the 7th curing day. Without any warning the plates failed suddenly after the occurrence of the first crack for the zero volume fractions. The crack occurrence and maintaining of the sample during loading were changed due to fibers addition. The specimens did not fail suddenly after occurrence of initial cracking for addition of 0.6%, 0.8% and 1% fiber . Randomly oriented fibers which cross the cracked section resisted the propagation of cracks and separation of the section. This caused an increase in the load-carrying capacity beyond the first cracking. It is observed that plain mortar exhibits greater flexural strength than the reinforced one. In the same time the addition of fibers enhanced energy absorption capacity for the samples in the 7th curing day. Here, the area under the load- deflection curve represents energy absorption capacity (toughness index) which is a measure of material capability to absorb energy and resist fracture under static or dynamic loads. The area under the curves founded for w/c=0.6 samples are 74.2, 200.2, 369.8 and 168.2 for 0%, 0.6%, 0.8%, and 1% fiber volume fractions respectively. While these areas founded for w/c=0.7 samples are 24.8, 133.7, 260.7 and 256.5 for 0%, 0.6%, 0.8%, and 1% fiber volume fractions respectively. It is observed that the area increase with the increasing of fiber volume fraction and the greater area amount seen in 0.8% fiber volume, which confirm again that the 0.8% fiber volumetric fraction is representing the optimal ratio.

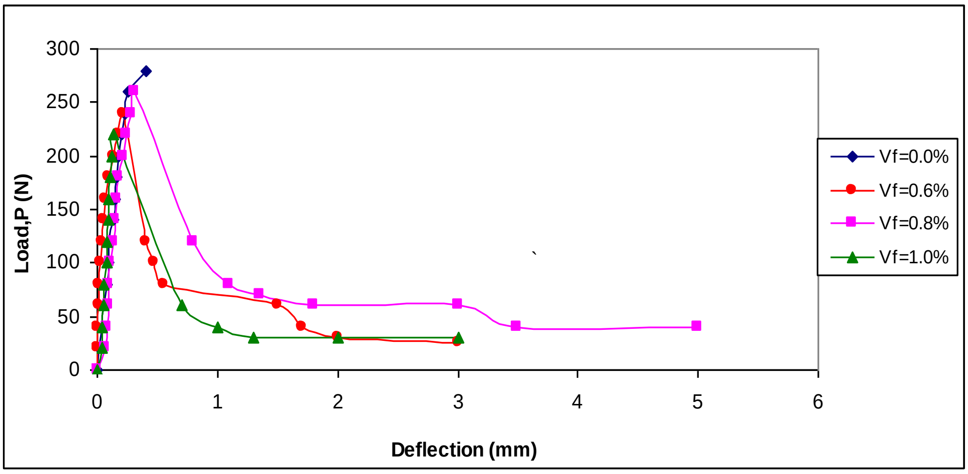

Figure (5) Load-deflection plot of different volume fraction of fibers for w/c = 0.6 for one way plates.

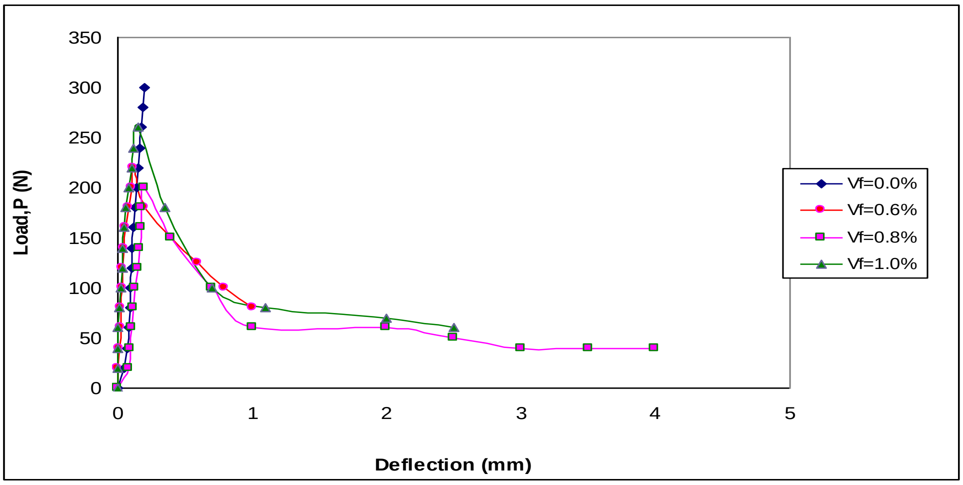

Figure (6) Load-deflection plot of different volume fraction of fibers for w/c = 0.7 for one way plates.

BEHAVIOUR OF THE SPECIMENS UNDER LOAD:

When loading increased, cracks appeared in the flexural span for all the plates and prisms and farther increase in load led to additional cracks and widening of some of the earlier cracks.

Ultimate load and deflections are increased considerably by the addition of higher volume fraction of fibers. Figure (1) shows tested specimens after loading. HHF acts as crack arresters which in turn restricts propagation of cracks and bridge the matrix along cracks length during loading. For further researches it is recommended to study the long term performance of human hair fiber reinforced composite.

CONCLUSIONS

1- HHF reinforced mortar can be obtained using conventional constituents of mortar and fibers, with due care in the selection ingredients of sand, superplasticiser, optimum percentage of fibre (from clean source), and proportioning of the mix.

2- The fibers are effective in resisting deformation at all initial and weak stages of loading from first cracks to failure.

3- It is found that the 0.8% is the optimum fibre percentage used with the mortar when samples of plane mortar without fibre and by adding different fibre percentage of human hair fibre were compared.

4- Energy absorption capacity and ductility factor improved considerably when fiber content increased, which makes using the HHF suitable for seismic force resistant structures.

Fibers which are too long tend to "ball" in the mix and created workability problem. Therefore, to get more homogeneous dispersion and avoiding balling of hair fibere, more studies are required to find randomly mixing methods without balling effect for gaining better result in another mortar or concrete testing researches.

REFERENCE

[1].Pickering,K.L.Properties and Performance of Natural Fibre Composites.Woodhead Publishing in Materials.2008

[٢]. Ganesan, N. P V Indira, and R Abraham. Behaviour of Steel Fiber Reinforced High Performance Concrete Members under Flexure. IE (I) Journal- CV, Vol.88,May 2007.

[٣]. Falkner, T.W. Falkner, Fiber Reinforced Concrete, Printed from: The technical advisor, June 1993.

[٤]. Ali, R. Khaloo. Behavior of Date-Leaf Fiber Reinforced Motar. ACI-Concrete international journal, Aug 1998.

[٥].David, Stephens. Natural Fiber reinforced concrete Block. 20th WEDC Conference (Affordable Water Supply and Sanitation),Colombo, Sri Lanka, 1994.

[٦]. Torgal, F. P. S. Jalali. Eco – Efficient Construction and Building Materials Springer 2011.

[٧]. Zheljazkov V. D. Assessment of Wool Waste and Hair Waste as Soil Amendment and Nitrite Source. Journal Environmental Quality. Vol,34, 2005 ,pp2310-2317.

[٨]. ACI Committee 544," State of the Art Report of Fiber Reinforced Concrete." Concrete International: Design & construction, V.4, No. 5, May 1982, pp. 9-30

[٩]. Rumualdi, J.P., and Batson, G.B., "Mechanics of Crack Arrest in Concrete ." Journal of the Enginnering Mechanics Division, ASCE, V.89, No. EM-5, June 1983, pp. 147-168.

[١٠]. Naaman, A.E.," Fiber Reinforcement For Concretes." Concrete international: Design & Construction, V.7, No.3, Mar. 1985, pp.21-25.

[١١]. Falkner,H. Z.Huang, and M. Teutsch. Comparative Study of Plain and Steel Fiber Reinforced Concrete Ground Slabs. ACI- Concrete international journal, Jan 1995.

[1٢]. Jackie Yen Lei Voo, and Stephen J. Foster. Variable Engagement Model for the Design of Fiber Reinforced Concrete Structures. 2003 ECI Conference on

Advanced Materials for Construction of Bridges, Buildings and Structures III,2005, Paper 2.

[1٣]. Wafa, and S.A.Ashour, F. F. Mechanical Properties of High-Strength Fiber Reinforced Concrete, ACI Materials Journal, V. 89, No.5, September-October 1992.

[1٤]. Akhtar, and Sh. Ahmad, J.N. The Effect of Randomly Oriented Hair Fiber on Mechanical Properties of Fly Ash Based Hollow Block for Low Hight Masonry Structures. Asian Journal of Civil Engineering, Vol.10, No.2, 2009, pp 221-228.

[1٥].Ahmad, M. Hasan. Behavior of Silty Clay Reinforced with Waste Human Hair as Randomly Fiber Reinforcemen. Zanco, Journal of pure and applied Sciences/ Salahaddin University- Hawler. Vol.21, No.2.2009

[1٦].ACI Manual,"Measurement of Properties of Fiber Reinforced Concrete",1999, Anual book Reported by ACI Committee 544.

[17].Soulcivic.Fiber Reinforced Concrete. Private document.2011.