THE INCORPORATIONS OF WOOD ASH AND PALM FIBERS FOR THE PRODUCTION OF HIGH PERFORMANCE MORTAR +

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Abstract:

This paper presents two stages: The first stage discusses the use of wood ash for the production of High Performance Mortar(HPM). The different weight percentages used for wood ash are:6,8,10,12, 14 and 16% as partial replacement of cement. Thus, the experimental tests includeddensity, compressive strength and flexuralstrength. The results illustratethat the wood ash decreases the density of HPM. Besides, the inclusion of10% ofwood ash as a partial replacement of cementgives the best compressive and flexural strengths of the HPM. Whereas, the second stage shows the use of optimum percentage of wood ash (10%) with different volumetric percentages of palm fibers (0.3, 0.6, 0.9, 1.2%) which are incorporated in HPM. The experimental tests included density, compressive strength , flexural strength and toughness performance according to ASTM C1018 and ASTM C1609. The results indicated that the use of palm fibers would reduce the density of HPM. The use of 0.6% of palm fibers with 10% of wood ash increase the compressive and flexural strengths by about 15 and 30%, respectively. Besides, the use of 0.9% of palm fibers enhances significantly the flexural toughness of HPM.

Keywords: **High performance mortar, wood ash, palm fiber.**

استخدام رماد فحم الخشب والياف النخيل لإنتاج مونة السمنت عالية الأداء

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المستخلص:

هذه الدراسة تتضمن مرحلتين : تهدف المرحلة الاولى إلى استخدام رماد فحم الخشب لإنتاج مونة السمنت عالية الأداء. تمت هذه الدراسة باستخدام نسب وزنية مختلفة من رماد الفحم حيث كانت النسب كالاتي: 6%, 8%, 10%, 12%, 14%, 16%. تم فحص نماذج مونة السمنت لكل من الكثافة ومقاومة الانضغاط ومقاومة الانحناء. النتائج بينت ان استخدام رماد الفحم يعمل على تقليل الكثافة. بالإضافة إلى ذلك فان استبدال 10% من رماد الفحم أعطت أفضل أداء مونة السمنت وخاصة بالنسبة لمقاومتي الانضغاط والانحناء. بينما تضمنت المرحلة الثانية استخدام النسبة المثالية من رماد الفحم (10%) مع نسب مئوية مختلفة من الياف النخيل وهي 0.3 و 0.6 و0.9 و1.2) مع مونة الاسمنت عالية الاداء. الفحوصات تضمنت الكثافة ومقاومة الانضغاط والانحناء واداء المتانة حسب المواصفات الأمريكية (ASTM C1018 and ASTM C1609).

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النتائج بينت بان استخدام الياف النخيل يقلل من كثافة مونة الاسمنت وان استخدام 0.6 من الياف النخيل مع 10% من رماد الفحم يزيد مقاومة الانضغاط والانحناء بنسبة 15 و 30% على التوالي. بالإضافة الى ذلك فان استخدام 0.9 % من الياف النخيل يحسن من متانة مونة السمنت عالية الاداء بشكل كبير.

Introduction:

The development of High Performance Concrete (HPC) has brought forth the needfor admixtures, both mineral and chemical, to improve theperformance of concrete. Silica fume (SF) is one suchmaterial. Many investigations reflecting the performanceof SF were conducted in the 1970s to 1980s. Promisingresults were shown by Malhotra and Carette [1].

Wood ash is generated as a by-product of combustion in wood-fired power plants, paper mills, and other wood burning facilities. Since wood is a renewable source of energy and environmentally benign friendly material, there will be increased use of wood in energy production in the future. As a result, there will be increased amount of wood ash generation[2].

The use of wood biomass as a source of renewable energy is gaining its popularity among the timber product industry and power production sector in several developed countries[3].

In the absence of proper disposal technique, the fine and lightweight wood ash produced poses serious air pollution and health hazards to humans. Therefore, the reuse of wood ash as a supplementary binder material in concrete is perceived as a viable and sustainable method for disposal of the waste in mass amounts without side effects to the environment [3].

Recent research [4] was performed to investigate the feasibility of the use of wood waste ash as a partial replacement material for the energy intensive processof hydraulic cement for concrete production. The tests showed promising results in that wood waste ash can suitably be used as constituent material in the production of structural grade concrete with acceptable mechanical and durability properties.

These findings provide a solution for the waste management problems of wood waste ash and also contribute towards minimizing the consumption of energy intensive hydraulic cement production of greener concrete material supplying the ever growing demand of the construction industry. Hence, incorporation of wood waste ash as cement replacement material in blended cement and concrete will be beneficial not only in environmental terms for concrete material but also in production costs of the aforesaid materials [4].

On the other hand, there has been a growing interest in utilizing natural fibers for making low cost construction materials in recent years. Knowledge of natural fibers use in cement composites, mechanisms of mechanical behavior, insulating behavior. has increased substantially. Many Research papers [5] indicated various advantages in the use of natural fibers in cement composites,such as, increased flexural strength, post-crack load bearing capacity, increased impact toughness, and improved bending strength [6]. Natural fibers also enhance mechanical and behave like reinforcement for the composites [7,8]. The major advantage of using natural fibers is that, they offer significant cost reduction and benefits associated with processing as compared to synthetic fibers. Hence, the material receives a lot of attention for replacing synthetic fibers [9]. However, due to increasing awareness on the environment and energy, special attention should be paid to natural fibers with a view to conserve energy and protect the environment. The addition of natural fiber also reduces the thermal conductivity of the composite specimens and yielded a lightweight product [10,11]. Someinvestigations have already been carried out on various mechanical and physical properties of concrete materials using natural fibers from coconut husk, sisal, sugar cane begasse, bamboo, jute, wood, akwara,elephant grass, water-reed, plantain and musamba, and cellulose fibers. These investigations [7,8,12] have shown encouraging results. A wide variety of natural fibers has been used for numerous applications, but whilst many of these show

considerable promise, the use of natural fibers to reinforce cement pastes, mortar and concrete stilt remains to be a subject of further research and investigation.
The main objective of the present study is to investigatethe effect of using different percentages of wood ash as partial replacements of cement on the properties of high performance mortar (HPM). Besides, the use of different percentages of palm fibers and study the effect of such fibers on the properties of HPM.

ManufactureofSpecimens:

The cement used in the mortar mixtures was ordinary Portlandcement a productof Iraqi cement produced byBadosh cement factory. The wood ashwas used as partial replacement of cement in different percentages to determine the optimum percentage of replacement.The chemical composition of Ordinary Portland and wood ash are given in Table1.
The superplasticizer (SP.)(Conplast SP1000,Fosroc Sdn. Bhd.) was adjusted to give the properties of the requiredflowability for all mortarmixes. The flow design for all mixes was 140-160%. The fine aggregate used is natural sand, whose fineness modulus is 2.86 and the maximum size less than 5 mm.
The palm fibers were produced by Fiber-X (M) Sdn. Bhd, and its characteristics are shown in Table 2 and Figure 1.
The mortar mixes A0 to A6 were prepared using 0, 6, 8,10,12,14 and 16% of wood ash as partial replacement of cement (by weight), respectively. The materials composition of Mortar mixtures are presented inTable 2.Besides, the mortar mixes A7-A10 were prepared using 0.3, 0.6, 0.9,1.2% of palm fibers based on volume fractions. All batches were prepared by using a mechanicalmixer conformingto the requirements of ASTM C305 [13].
Each batch of mortar was produced in a pan mixer. Cement, sand, water and superplasticizer were first added to the mixer and mixed for 3 minutes. Then the wood ash was added and the mixture was further mixed for 2 minutes. Lastly the palm fibers were disseminated in the mortar mixes and mixed for 3 minutes.
The flow test forthe mortar mixes was performed according to ASTM C1437 [14]. Freshmortarmixtures werecast into 50 mm cube moldsand prismatic (40 × 40 × 160 mm) steel molds. Thespecimens were left in the molds for 24 hours at room temperature of20 °C. After demolding, the specimens werekept in a curingroom till the age of test(28 days). After the curing period,the mortar cube specimens were subjected to compressive load according to ASTM C109 [15]. The prismatic mortar specimenstested in flexural strength, toughness indices and flexural toughnessaccording to ASTM C348 [16]ASTMC1018 [17] and ASTM C1609 [18], respectively. The methods of flexural toughness determinations according to mentioned specifications are shown in Figure 2 and 3.The density test for all the mortar specimens was carried out according to ASTM C642 [19] , where the saturated densities have been determined.

Results and discussion:

The flow test results for HPM mixes are shown in Table 3. It can be seen from this Table that the inclusion of wood ash gives an acceptable performance in term of flow. Thus,for different percentages replacement, the target flow of 140-160% was obtained with less amount of superplasticizer[3]. On the other hand, the use of palm fibers reduces the flowability of mortar and thus higher percentages of superplasticizer were used to maintain the designed flow [20].

Table 4reports the mean test valuesof density, compressive strength and flexural strength for HPM mixes.

From these results, it can be noticed that theinclusion of wood ash in the HPM mixes reduces the density considerably. This can be attributed to the specific gravity of wood ash which is less than the specific gravity of cement[21, 22]. Figure4illustrates the relationship between wood ash and density of HPM.
Regression analysis on the percentage of wood ash and density for HPM of mortar mixes shows a strong correlation between them as shown for the following equation:

$y = 0.05x^3 - 1.908x^2 + 7.224x + 2349.7, R^2 = 0.9912$ ....(1)

On the other hand, the use of palm fibers would significantly reduce the density of HPM. As the inclusion of palm fibers increase, the density of HPM decreases due to their specific gravity[21]. Figure 5 shows the relationship between palm fibers and density of HPM.
Regression analysis on the percentage of palm fibers and density for HPM of mortar mixes shows a strong correlation between them as shown for the following equation:

$y = 23.81x^2 -98.571x + 2282.3, R^2 = 0.9899$ ....(2)

The compressivestrength resultsfor HPM mixes (Table 4) show that the use of wood ash up to 10% increases the compressive strength of HPM. The use of 10% wood ash increasesthe compressive strength of HPM by about 15%. This observation can be attributed to the increased calcium silicate hydrate (C-S-H) gel formation within the cement paste matrix microstructure of wood waste ash by pozzolanic activity [3,4].However, the use of more than 10% of wood ash reduced the compressive strength considerably. Figure 6 shows the relationship between wood ash and compressive strength of HPM.
Regression analysis on the percentage of wood ash and compressive strength for HPM of mortar mixes exhibits a strong correlation between them as shown for the following equation:

$y = 0.143x^3 - 5.118x^2 + 54.01x - 121.4, R^2 = 0.963$ ....(3)

On the other hand,it can be concluded that the increase of palm fibers up to 0.6 % would provide further increase to the compressive strength of the HPM due to the reduction in porosity. However, the inclusion of more than 0.6% of the palm fiber would reduce such increment in thecompressive strength of HPM and this is attributed to the voids introduction in the mix due to excessive fiber content that may lead to reduction in bonding and disintegration [21,22]. Figure 7 illustrates the relationship between wood ash and compressive strength of HPM.
Thus, Regression analysis on the percentage of palm fibers and compressive strength for HPM of mortar mixes shows a strong correlation between them as shown for the following equation:

$y = 15.873x^2 + 11.981x +54.123, R^2 = 0.968$ ....(4)

Theflexural strength results of HPM mixes are shown in Table 4. The use of 10% of wood ash as partial replacement of cement gives an increase of about 14 %. However a reduction in flexural strength of HPM was obtained with the inclusion of 16% of wood ash in the mortar mix.

Regression analysis on the percentage of wood ash and flexural strength for HPM of mortar mixes reveals a considerable correlation between them as shown for the following equation

$y = -0.001x^3 + 0.027x^2 - 0.005x + 6.452$, $R^2 = 0.890$ ....(5)

Figure 8 shows the relationship between wood ash and flexural strength of HPM.
Furthermore, the use of palm fibers has also increased the flexural strength of HPM. The results showed that theincrease of the flexural strength is obtained up to 0.6% volumetricfraction of palm fiber used in the mix, and beyond this percentage, thedecrease in flexural strength is significant. This is due to formation ofvoids in the matrix, which causes the flexural strength to reduce. Thecomparison between no-palm fiber mix with 0.6% of palm fiber mix, leadsto a conclusion that the flexural strength has increased by about 14 %,when the palm fiber is included in HPM mix[22-24]
Regression analysis on the percentage of palm fibers and flexural strength for HPM of mortar mixes reveals a considerable correlation between them as shown for the following equation

$y = 3.1746x^2 + 3.5429x + 7.9886$, $R^2 = 0.890$ ....(6)

Figure 9 shows the relationship between palm fibers and flexural strength of HPM.

Table5 illustrates the results of the flexural toughness in order of I-5 according to ASTM C1018 and also flexural performance due to ASTM C1609.. It can be observed that the fiber fraction up to 0.3% has no effect on the toughness performance but beyond this percentage it has increased as the fiber fractionincreased too. Therefore, the best performance of flexural toughness has obtained at 0.9% of palm fibers [22]. Thetoughness are found to be improved with the increasing fiber content,and the behavior indicates the ability of fibers in arresting cracks at bothmicro-and macro–levels. At micro-level, fibers inhibit the initiation ofcracks, while at macro-cracks; fibers provide effective bridging andimpart sources of toughness and ductility [24]. Thiswas also supported by other researchers [25],whereas the flexural toughness can be enhanced as the fiber volumefraction is increased and similarly higher values of the flexuraltoughness can be achieved at higher fiber volume fractions.

Conclusion:

This study was conducted to assess the properties of high performance mortar (HPM)produced by adjusting the percentage of superplasticizer with different percentages of wood ash as partial replacements of cement (0, 6, 8, 10, 12, 14and 16%).Besides, different percentages of palm fibers(0.3, 0.6, 0.9 and 1.2%) were included with the optimum percentage of wood ash. Thefollowing conclusions are drawn from the present study:
1-The use of wood ash decreases the density significantly.
2-The use of 10% wood ash increases the compressive and flexural strengths of HPM by about 10 and 14%, respectively.
3- The density of HPM is found to be affected by the inclusion of palm fibers, and thus such fibers would significantly reduce the density of HPM due to their specific gravity.
4-The inclusions of 0.6% of palm fibers with 10% wood ash in HPM enhanced the compressive strength and the flexural strength by about 15 and 30%, respectively.
5- The flexural toughness performance can be improved due to palm fibers. The best results in this property for HPM has been obtained with 0.9% of palm fibers.

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Tables:

Table (1): Physical characteristics of Ordinary Portland cement.

Test	Result	IQS : 5/1984
Initial setting time (minute)	150	Min. 45 minute
Final setting time (minete)	260	Max. 600 minute
Fineness (Blain m^2/kg)	280	Min. 230
Compressive strength of 5mm cubic Morter samples (MPa)		
3 days	22	Min. 15 MPa
7 days	29	Min. 23 MPa

Table (2): Chemical composition of Ordinary Portland cement and wood ash used.

Constituent	Ordinary Portland Cement % by weight	Wood ash % by weight	Limits of IQS : 5/1984 for ordinary Portland cement
Lime (CaO)	64.64	22.4	-
Silica (SiO_2)	21.28	45.5	-
Alumina(Al_2O_3)	5.60	7.5	-
Iron Oxide(Fe_2O_3)	3.36	12.8	-
Magnesia(MgO)	2.06	1.8	$\leq$ 5%
SulphurTrioxode (SO_3)	2.14	3.1	$\leq$ 2.8%
N_2O	0.05	0.8	
Loss of Ignition	0.64	4.3	$\leq$ 4%
Lime saturation factor	0.92	-----	-
C_3S	52.82	-----	-
C_2S	21.45	-----	-
C_3A	9.16	-----	-
C_4AF	10.2	-----	-

*** The chemical tests were done in Badosh cement factory.**

Table (3): Characteristics of palm fiber

Fiber properties	Quantity
Average fiber length	30 mm
Average fiber width	21.13 µm
Tensile strength (MPa)	21.2
Elongation at break (%)	0.04
Specific gravity	1.24
Water absorption %, 24/48 hrs	0.6

Table (4): Flow results of mortar mixes used

Index	Cement kg/m^3	Wood ash kg/m^3	Water kg/m^3	SP % of cement	Sand kg/m^3	W+SP/B*	Palm fiber,% by volume	Flow %
A0	600	-----	240	1.6	1400	0.40	---	160
A1	564	36	240	1.8	1400	0.40	---	160
A2	552	48	240	2.0	1400	0.40	---	155
A3	540	60	240	2.0	1400	0.40	---	155
A4	528	72	240	2.0	1400	0.40	---	150
A5	516	84	240	2.2	1400	0.40	---	150
A6	504	96	240	2.2	1400	0.40	---	150
A7	540	60	240	2.2	1400	0.40	0.3	140
A8	540	60	240	2.3	1400	0.40	0.6	140
A9	540	60	240	2.4	1400	0.40	0.9	145
A10	540	60	240	2.5	1400	0.40	1.2	140

***w= water, B=Biner(cement + wood ash)**

Table (5): Test results for the properties of high performance mortar

Mix Type	Silica fume %	Wood ash%	Palm fibers	Compressive strength MPa	Flexural Strength MPa	Density kg/m^3
A0	--	--	--	49.4	7.0	2350
A1	--	6	--	50.6	7.1	2330
A2	--	8	--	52.3	7.2	2320
A3	--	10	--	54.5	8.0	2280
A4	--	12	--	37.3	7.5	2240
A5	--	14	--	23.0	7.3	2220
A6	--	16	--	20.6	6.8	2180
A7		10	0.3	55.2	8.7	2260
A8		10	0.6	56.6	9.1	2240
A9		10	0.9	51.8	8.5	2210
A10		10	1.2	45.6	7.7	2200

Table (6): Toughness indices and flexural toughness of high performance mortar

Mix Type	Palm fibers %	Wood ash%	Toughness Index I-5	P_p (KN)	L/600 mm	P^D_{600} KN	L/150 mm	$P_{D\ 150}$ (KN)
A0	--	--	---	250	---	---	---	---
A1	--	6	1	253	---	---	---	---
A2	--	8	1	257	---	---	---	---
A3	--	10	1	285	---	---	---	---
A4	--	12	1	267	---	---	---	---
A5	--	14	1	260	---	---	---	---
A6	--	16	1	243	---	---	---	---
A7	0.3	10	1	311	0.20	260	0.80	143
A8	0.6	10	1.68	325	0.20	300	0.80	152
A9	0.9	10	1.89	303	0.20	270	0.80	178
A10	1.2	10	1.61	275	0.20	232	0.80	172

Figures:

Figure (1): Palm fibers used in the study

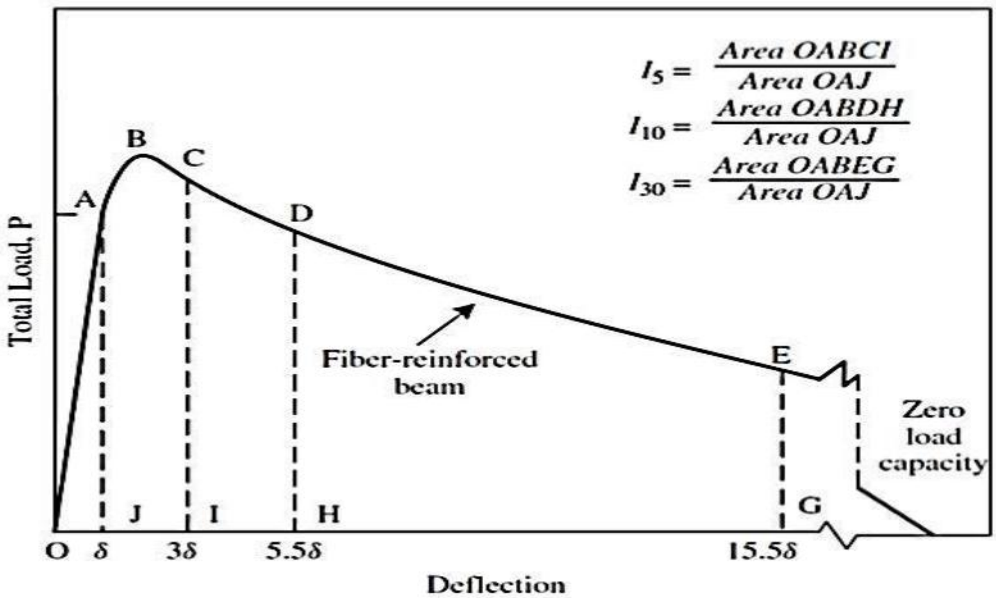

Figure (2): Toughness indices determination according to ASTM C1018.

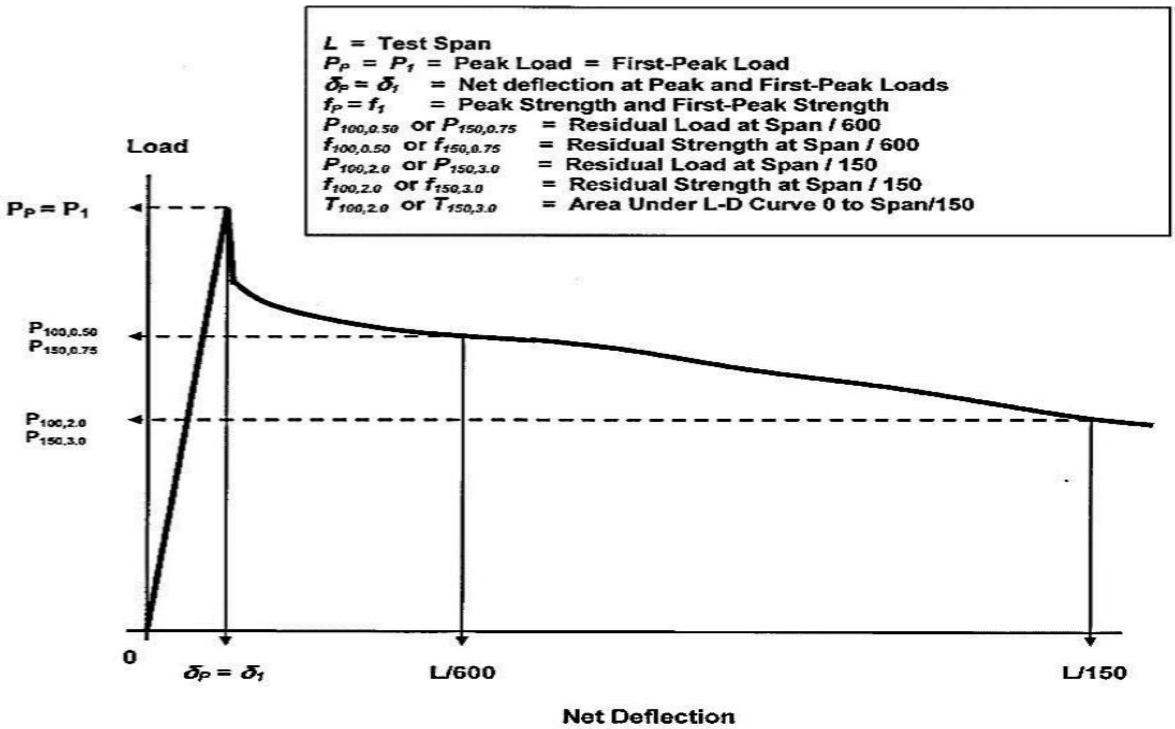

Figure (3): Flexural toughness Definition according to ASTM C 1609.

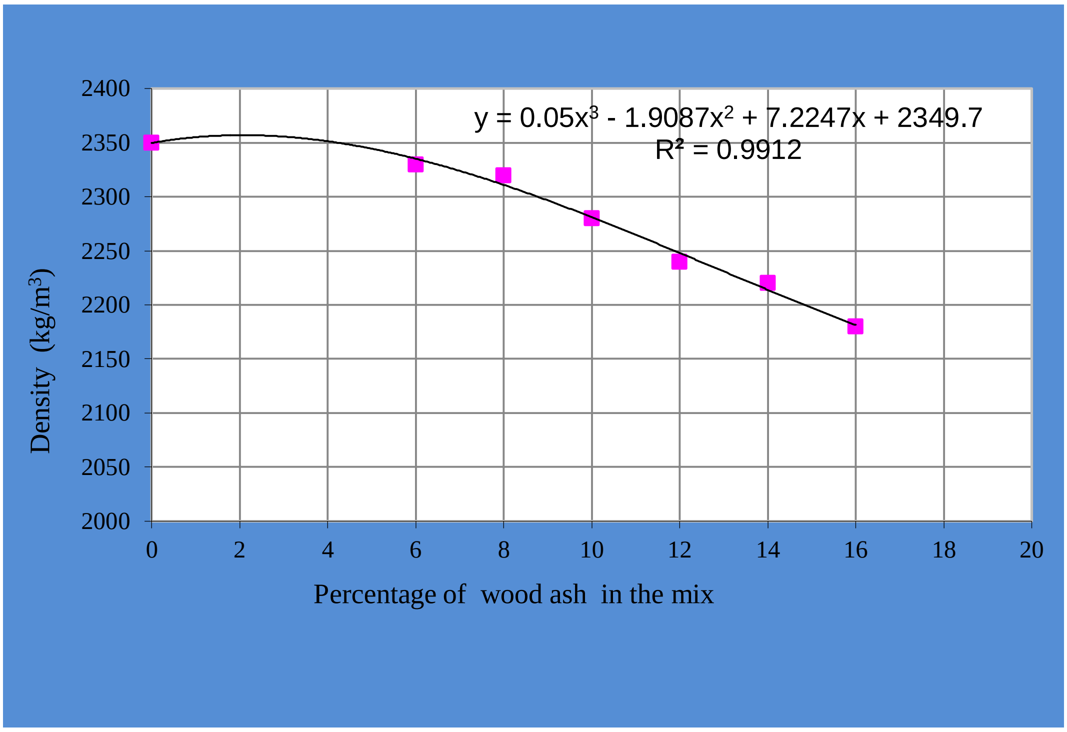

Figure (4): Relationship between wood ash and density of HPM.

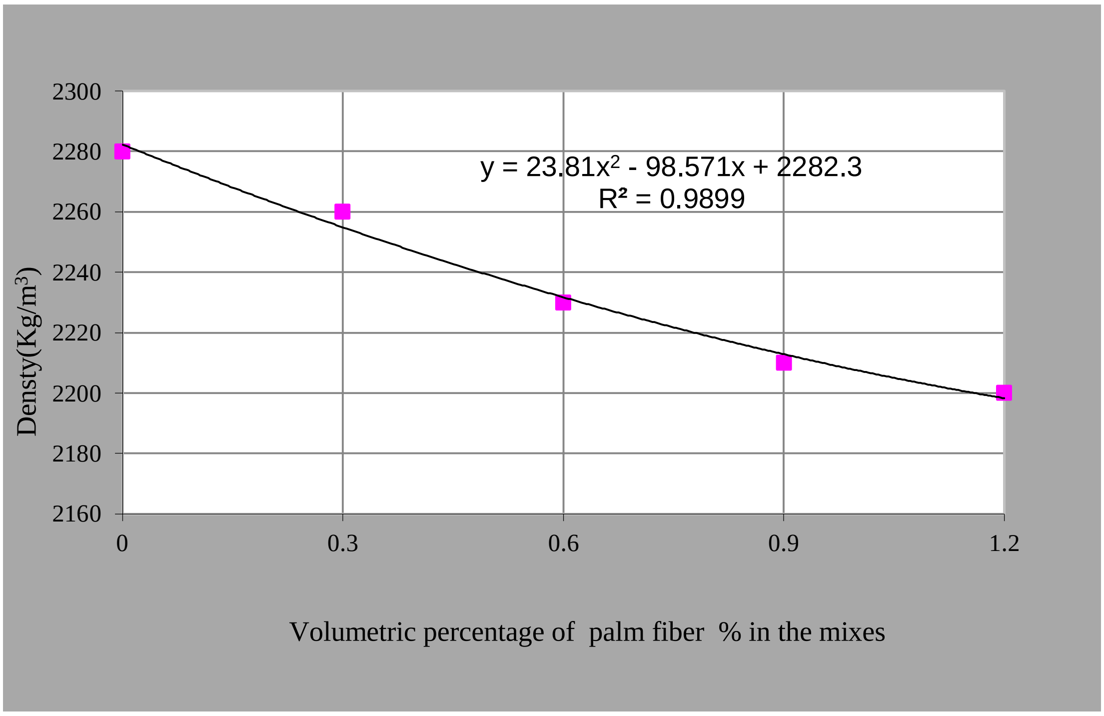

Figure (5): Relationship between palm fibers and density of HPM

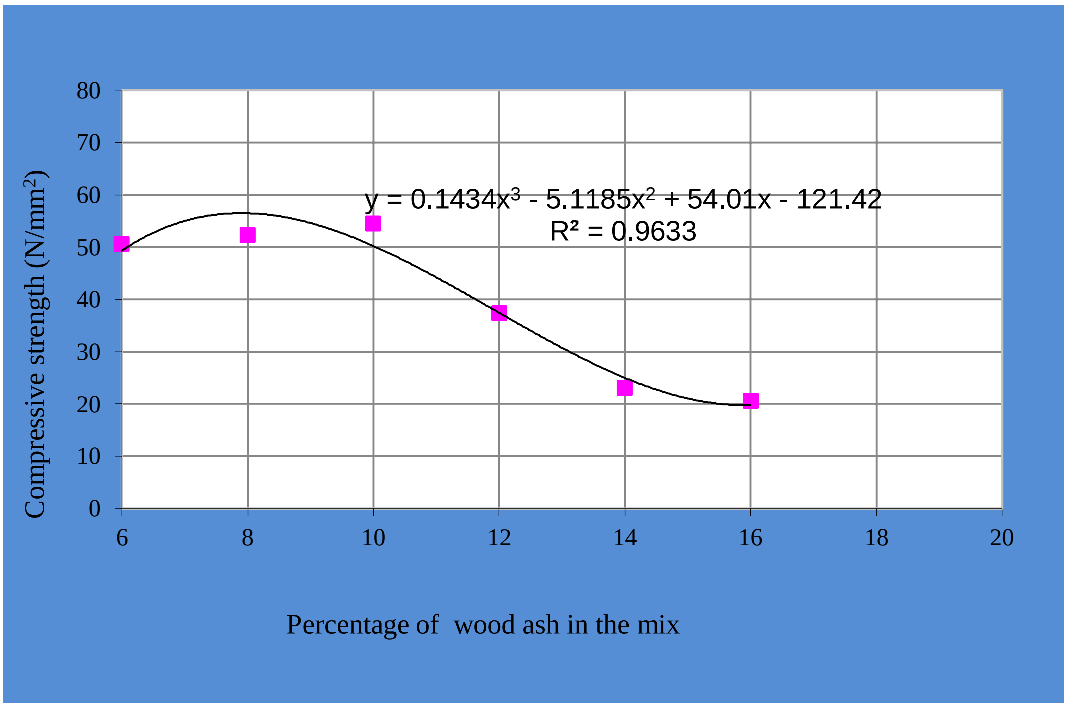

Figure (6): Relationship between wood ash and compressive strength of HPM

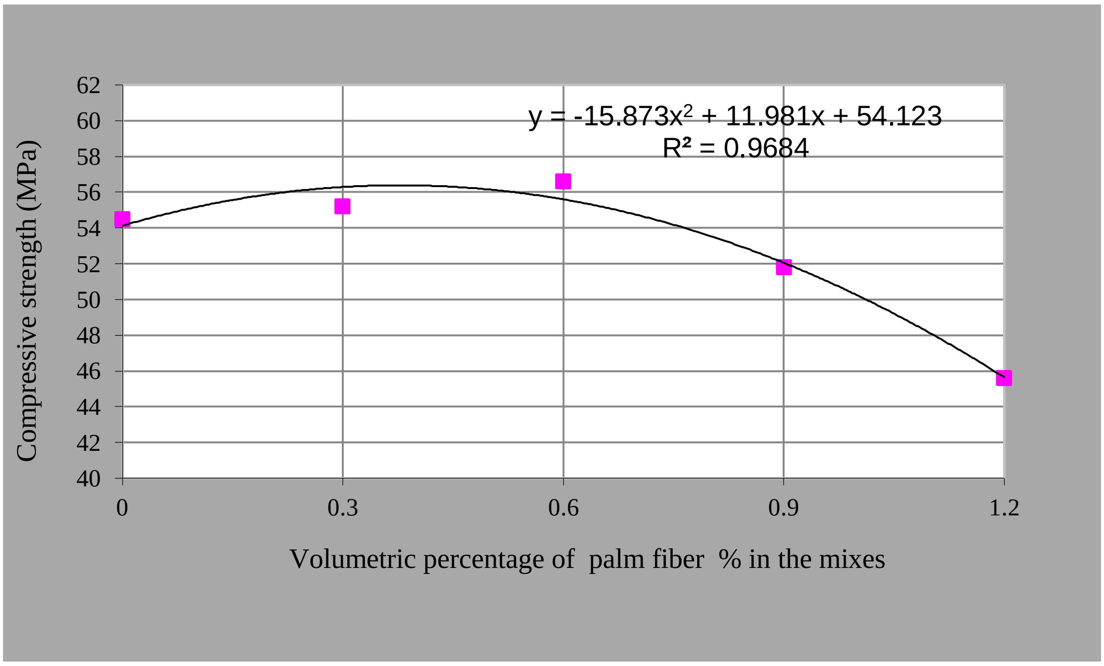

Figure (7): Relationship between palm fibers and compressive strength of HPM

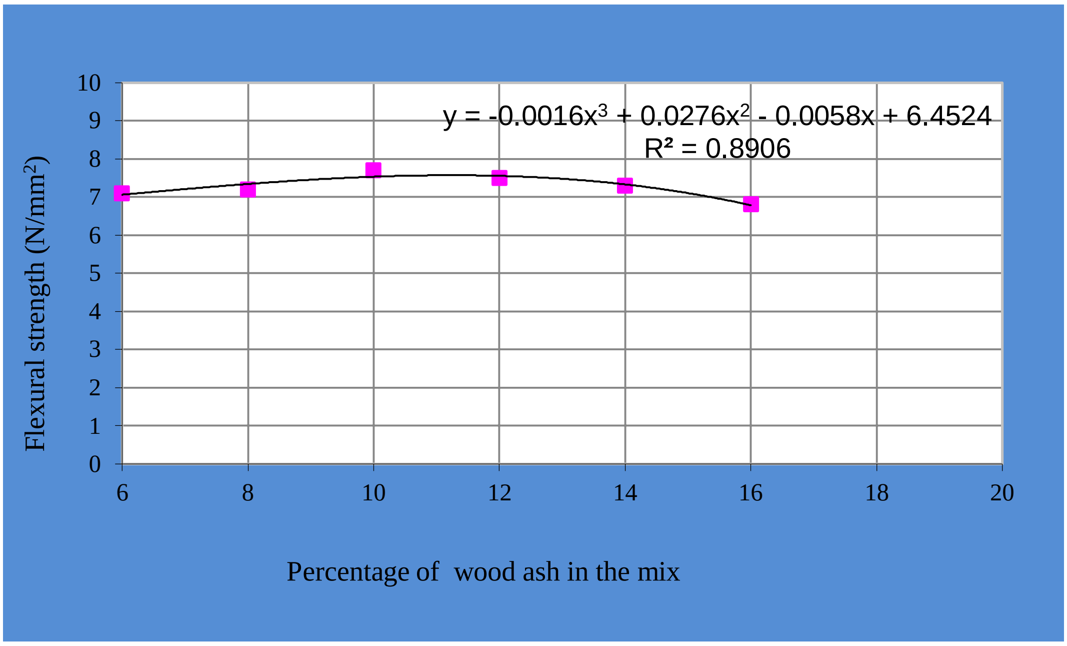

Figure (8): Relationship between wood ash and flexural strength for mortar specimens

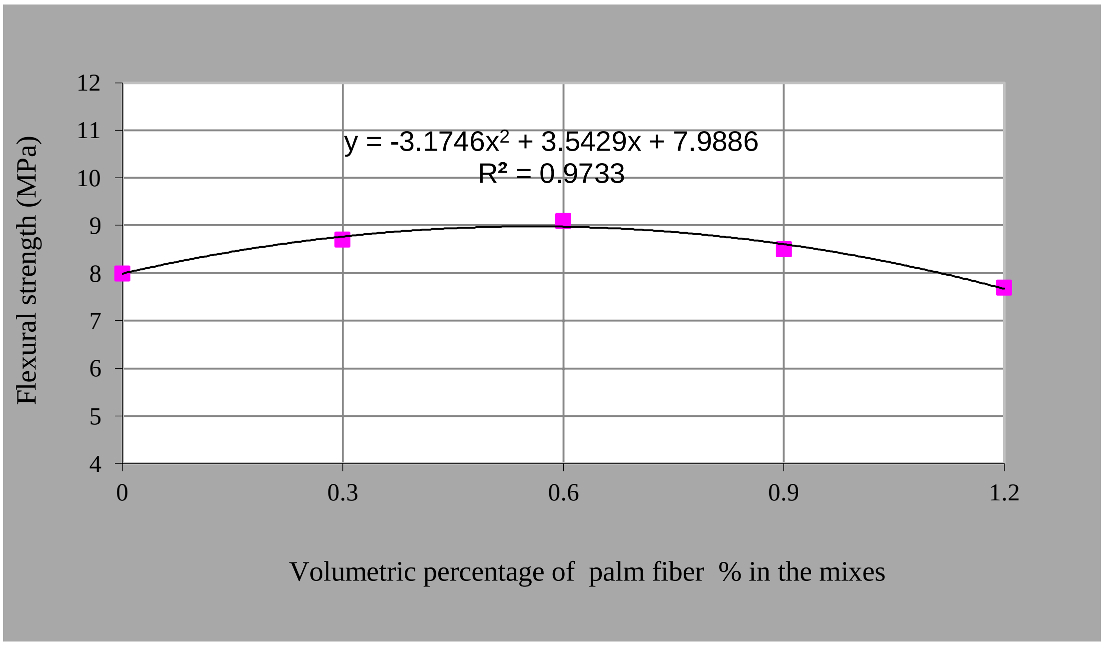

Figure (9): Relationship between palm fibers and flexural strength of HPM