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Investigation of Ferrocement Bricks Properties With Different Recycled Coarse Aggregates

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Abstract – *This study is aiming in recycling the construction wastes in an experimental way in order to save the environment and to produce ferrocement bricks with good properties. The experimental program including production of ferrocement bricks by partially replacing cement with 30% fly ash; and 50% of coarse aggregates with recycled concrete wastes (RCA) and recycled clay bricks (RBA). About 96 samples with different mix proportions were produced; half of them were strengthen with a mesh. The tests were compressive strength, density, absorption and durability of brick against chloride effect; they tested after 7, 14 and 28 days of curing under ambient temperature.*

The results indicates that compressive strength is decreasing by adding the waste aggregates but RCA gives better behavior by reduction of 30% than control sample with mesh and 23% than control samples without mesh. Based on this investigation; it was discovered that the best result was to produce ferrocement bricks with mesh replacing the cement with fly ash (30%) as well as replacing the coarse aggregate by 50% of recycled concrete as it will protect environment against wastes and reducing CO2 emision by reducing cement consumption. Mean while; this ferrocement brick is durable and lighter in density.

Keywords — *Ferrocement bricks, recycled concrete, recycled clay bricks, Chloride effect, Compressive strength.*

I. INTRODUCTION

Considering that concrete and brick waste account for a large proportion of construction and demolition waste and that other components have specific recycling paths, waste materials as aggregate in concrete blocks could be used in recycled concrete [1]. Solid waste produced from construction and demolition activities amounts to several million tons globally, and one of the prominent wastes is brick waste. In recent years, there has been increasing in the number of researches carried out on recycling brick aggregates (RBA) to produce more eco-friendly concrete [2].

Several investigations show that recycled brick aggregate could be used to substitute the natural coarse and fine aggregate in mortar and concrete. Most investigations involved the study of mechanical strengths since strength is one of the most important parameters used in the design. The investigation found that by replacing 50% of aggregate with RBA, the compressive strength of concrete slightly increased [3]. While [4] noticed a reduction in 28-day compressive strength as much as 14% at brick aggregate replacement up to 50%. The reduction in flexural strength was insignificant at all replacement levels. Also, the water permeability index of concrete containing up to 50% brick aggregate was almost twice the index of control concrete.

Also, several researchers were conducted on recycled concrete aggregate (RCA) and its effect on concrete. The statistical analysis showed that RCA derived from crushed concrete consists of 65–80 vol% of natural coarse and fine aggregates and 20–35 vol% of old cement paste [5].

The higher portion of attached mortar and the weaker interface between aggregate and mortar in RCA lead to lower concrete quality such as low compressive strength and poor durability. It was also reported that the use of RCA leads concrete to have higher shrinkage and creep strains [6]. It was suggested that a good RCA should meet certain criteria to be suitable for use in reinforced concrete. These include an aggregate relative density of 2.3 or higher, a maximum mortar content of 50%, and maximum water absorption of 3%. Some practice codes restrict the use of RCA with water absorption capacity greater than 7–10% to be used in structural concrete [7].

Another important aspect that affects the environment is cement. The manufacturing process of cement emits a massive amount of CO2. In 2016, world cement production generated around 2.2 billion tons of CO2 - equivalent to 8% of the global total of CO2 emissions. More than half of that came from the calcination process [8]. There have been a lot of researches in the field of cement replacement materials such as fly ash, rice husk ash, slag, and silica fume to reduce the consumption of cement and consequently CO2 emission.

Fly ash is generated from the coal combustion process as an industrial by-product. The successful application of fly ash will reduce cement consumption and also eliminate the waste disposal cost. The fly ash has been adopted widely in the construction industry as a binder replacement due to its pozzolanic activity, low water demand, reduced bleeding, and less heat evolution [9].

Class F fly ash contains a small quantity of lime. Thus, compressive strength is reduced with the increment of fly ash content in concrete. However, due to the pozzolanic activity of fly ash, the compressive strength increased in later stages of curing [10]. With the addition of class F fly ash, the compressive strength of concrete after 28-d curing was lower and decreased sharply with the increment of fly ash content. However, the compressive strength of 30 and 40% fly ash concrete increased gradually up to 180 d due to the pozzolanic reaction [9].

In this study, the mechanical and durability of ferrocement bricks was assessed using recycled concrete aggregate (RCA) and recycled bricks aggregate (RBA) in addition to class F fly ash as cement replacement material. To accomplish this, compressive strength, density, and chloride effect were determined after different curing periods.

II. Materials

he ordinary Portland cement with a grade of CEM I 42.5N following the Egyptian Standard Specification [11]. Water-to-cement ratio of 0.45 and fly ash type F were used as the binder materials as cement replacement material. Fly ash type F has been used to increase brick durability and overcome the effect of recycled aggregate on strength.

Water used was clean drinking fresh water free from impurities is used for mixing and curing the plates tested according to Egyptian Code Practices [12].

The fine aggregate was natural siliceous sand sizes less than 5 mm. It was clean and nearly free from impurities with the modulus of fineness of 2.7 a specific gravity of 2.6 t/m3. The coarse aggregate was limestone with a specific gravity of 2.5 t/m3 and maximum nominal size of 10 mm. Coarse and fine aggregates characteristics satisfy the Egyptian code of Practices [12].

Two types of recycled aggregates were used: the first is the recycled concrete aggregates (RCA) which were collected from a demolishing site and the other is the recycled brick aggregates (RBA) which were obtained from crushing of some clay bricks, figure 1. Both recycled aggregates crushed then the particle size distributions of both the RCA and RBA were carefully adjusted by using sieves of different sizes, removing the very large and very small partials.

Superplastizer was used to increase the strength by reducing the water content. Its characteristics satisfy the Egyptian code of Practices [12].

Square welded wire reinforcement mesh with the dimension of 10 x 10 mm has been used, figure 2. Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011).

Fig. 1 The expanded reinforcement mesh

III. Methodology

Two main mixes were made with a constant W/C ratio one with mesh and the other without it. For each type of the two mixes, there were three other mixes in addition to the control mix; one using ordinary coarse aggregate, another using RCA, and the last using RBA. All mixes are using with fly ash as cement replacement material with a constant percentage of 30% to increase durability and long-term strength. Also, the coarse aggregate replacement was with a constant percentage of 50%. Thus, there are a total of 8 mixes were made with total of 96 samples of concrete brick tested at 7, 14, 28 days. The mix ratio was 1:2:4 for cement: sand: limestone respectively. Tables 1 gives the details of the replacing materials mix proportion for the different mixes. The sample's dimension was 6 cm × 12 cm × 25 cm. The curing time was after 24 hrs of molding in normal condition. The samples for the chloride effect were put in a solution with 0.5% chloride salt for 28 days more.

Table 1: The mix proportion for fly ash and recycled coarse aggregate

Mix No.		Materials		
		Fly Ash	**RBA**	**RCA**
Mesh	M0	-	-	-
	M1F	30%	-	-
	M2FRBA	30%	50%	-
	M3FRBA	30%	-	50%
No Mesh	NM0	-	-	-
	NM1F	30%	-	-
	NM2FRBA	30%	50%	-
	NM3FRBA	30%	-	50%

A brick mold, fig. 2-a, was designed and manufactured to cast the ferrocement bricks. The forms were prepared and the reinforcing steel mesh was formed in a box-shaped form and placed in each mold. The components of the mortar were mixed and cast in each mold to the required thickness as shown in fig. 2-b.

(2-a) (2-b)

Fig. 1 Preparation and casting ferrocement bricks

The bricks were left for 24 h in the mold before removal. At the end of this step, the ferrocement bricks are produced. The bricks then were submerged for 7, 14, and 28 days and then tested. The tests were compression strength, weight, and durability against chloride solution.

III. Results and Analysis

A. Compressive test

The samples were tested after different curing durations 7, 14, 28 using ELE universal testing machine with capacity of 1000 KN in accordance with Egyptian specification ESS 1292-2 / 2015.

The mean compressive strength of ferrocement bricks samples for the different mixes presented in fig. 3. It can be seen that, the control samples without fly ash exhibit a high compressive strength at 28 days of curing as M0 gives 21 MPa and NM0 gives 19 MPa. The control samples with fly ash M1F and NM1F give strength about 18 MPa and 16 MPa respectively less than control sample by 12% and 25%.

It has been noticed that samples with RBA gives strength lower than RCA. Mixes M2FRBA and NM2FRBA give strength 11 MPa and 8 MPa less than M1F, NM1F by about 40% and 50%. While the situation was better for samples with RCA. Mixes M3FRCA and NM3FRCA give compressive strength of about 15 MPa and lower than control sample with fly ash (M1F, NM1F) by 20% and 13%.

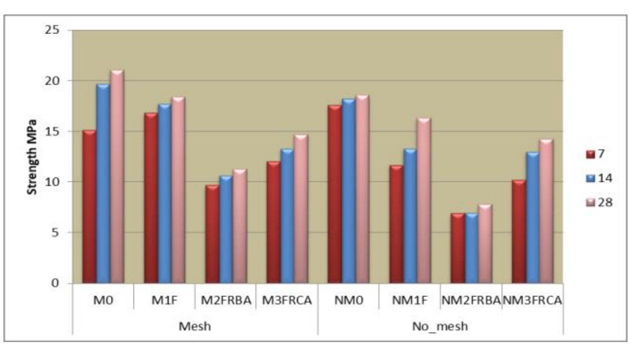

Fig. 2 Compressive strength for the 8 mixes

And for comparison between the mix samples with mesh and the same mix samples but without, fig. 4 represent this comparison. It was found that samples with natural aggregates and mesh will increase the strength by 12%. For RBA, the usage of mesh will increase strength by 30% while for RCA it makes no difference as it will increase only 3%.

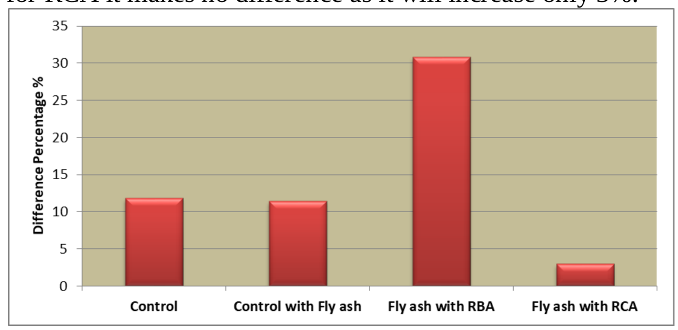

Fig. 3 Difference between samples with mesh and without mesh for the same mix

B. Weight and density

Fig. 5 shows the average weight of samples for each mix. The weight is measured 4 times for each mix; after 24 hrs of molding and after each period of curing (7, 14, 28). It was noticed that there is a small difference in weight between samples and that the weight ranged between 3.9 kg to 4.8 kg. After 28 days, the largest weight noticed for control mix without mesh (NM0) while the lowest noticed for control mix with fly ash, mesh and natural aggregate (M1F). It's obviously noticed that RBA increase the samples weight as it's absorption capacity of water increases with time.

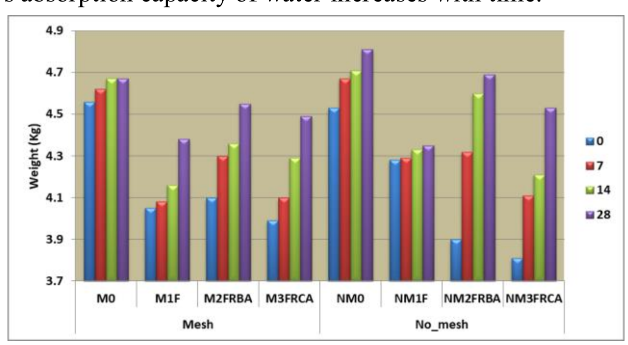

Fig. 4 Average weight measurement for the 8 mixes

Fig. 6 shows the weight difference for the samples from day 1 till 28 days of submerging in water. It was noticed that the difference for samples with recycled aggregates was larger than for bricks with limestone aggregates; and that their difference is almost equal. This means that this these types of aggregates is absorbing water more than the normal aggregates. Also, the presence of mesh reduce the difference in weight for almost all samples.

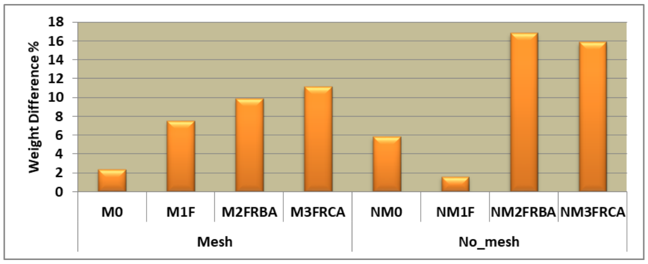

Fig. 5 weight difference between day 1 and day 28 for the 8 mixes

For density, it was measured using samples weight at day 1, as shown in Figure 7. It was noticed that the density almost the same for RCA and RBA which is lower than control samples by about 12% and 10% for samples with mesh and by 16% and 14% for samples without mesh respectively. Also, it was found that adding fly ash will reduce the density even with using normal aggregates by 11% with mesh and by 6% without mesh.

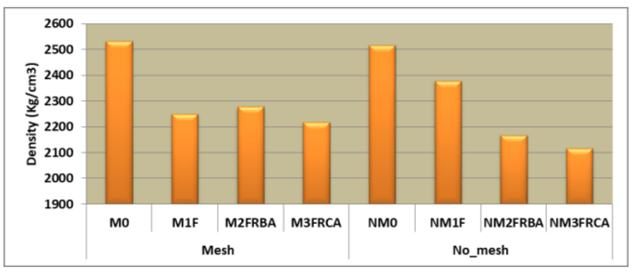

Fig. 6 Density for the 8 mixes

C. Chloride effect

Fig. 8 shows the effect of chloride solution on the compression strength of bricks after 28 days of submerging. It was noticed that there was a reduction in strength ranged between 8 % till 19%. The least affected samples were samples with mesh, as it strengthened the brick. Also, the most affected was the samples with recycled aggregates of RBA with reduction of 13% for samples with mesh and 19% for samples without mesh.

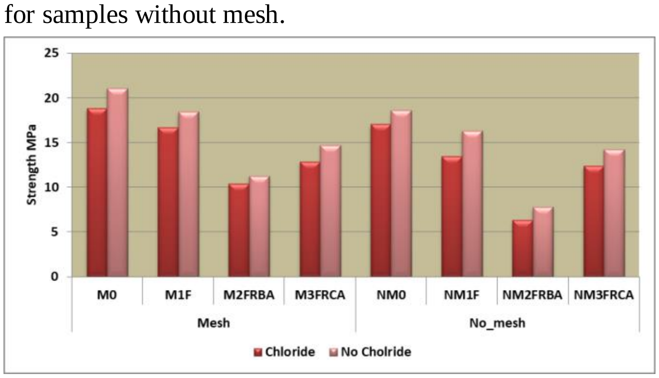

Fig. 7 Chloride effect on compression strength for the 8 mixes

For weight, the reduction due to chloride effect was with smaller values. Figs. 9 shows the effect of chloride solution on the weight of bricks samples after 28 days of submerging. It was noticed that bricks with RCA and fly ash (M3FRCA and NM3FRCA) has the minimum effect as its weight reduced by only 0.4%. While the maximum effect was noticed on control bricks with normal aggregates (M0, NM0) as its weight was reduced by 4%.

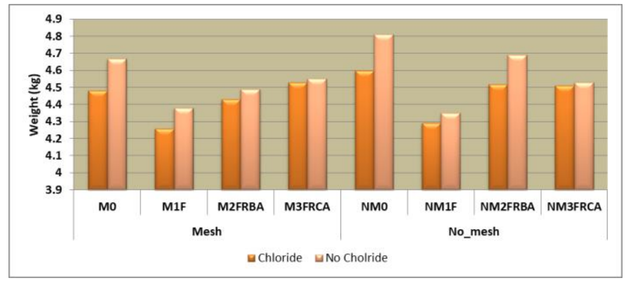

Fig. 8 Chloride effect on the weight for the 8 mixes

A comparison has been done for the reduction of weight and strength due to chloride effect (fig. 10). It was obviously noticed that samples without mesh has the gretest reduction in weight and strength than samples with mesh. Also, samples with RBA and mesh (M2FRBA) gives the best behavior in durability against chloride solution as it has the lowest reduction in weight and strength.

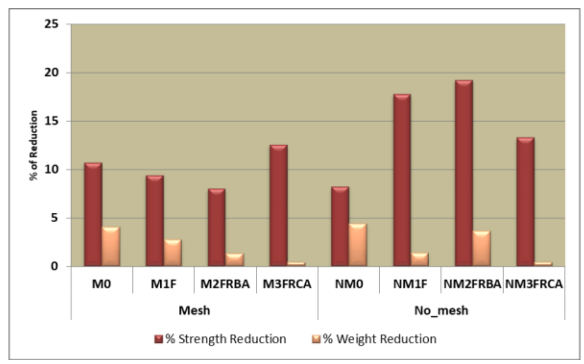

Fig.10 % of Reduction for weight and strength due to chloride effect for the 8 mixes

IV. CONCLUSIONS

This paper has presented an experimental investigation on the effect of the replacement of natural coarse aggregates with recycled aggregates on the durability, density and compressive strength of the strengthened ferrocement bricks. The experiments involved the use of two types of recycled aggregates, namely RCA and RBA, and two casting was conducted (with mesh and without mesh). From the obtained experimental results, the following conclusions can be drawn;

- The bricks behavior influenced by the replacing the normal aggregate by recycled one, this appears in the compression strength, density and durability of these samples. Also using ferrocement techniques in production of this bricks has a great effect on improving the bricks behavior.
- The density decreases with replacing the aggregates by recycle aggregates and it gives the minimum value by adding RCA.

- The compressive strength decreases in general with the addition of recycled aggregates but the compressive strength was better using RCA than with RBA.
- The durability against chloride solution was better for ferreocement bricks, specially for bricks with RBA as the reduction in weight and strength was only 1.3% and 8% respectivally.
- A long term behavior for this ferrocement bricks is recommended to be investigated in future and also its durability against sulfure acids.

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