ENGINEERING CHARACTERISTICS OF ECO - FRIENDLY COMPOSITE MADE FROM STEEL SLAG - RICE HUSK AND GYPSUM

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ABSTRACT

Steel slag waste is a by-product from steel production and rice husk is a renewable waste produced from rice peeling. These wastes can be used as Eco - Friendly building materials instead of polluting materials like gypsum and cement. The aim of this work is to investigate the behavior of building materials resulting from the mix of gypsum, steel slag and rice husk in different percentages.

The work was conducted in three phases. The first phase was conducted to investigate the effect of replacing gypsum by steel slag waste with different weight ratio (namely, 0, 10, 20, 30, 40, and 50%) on the compressive strength of gypsum steel slag mixture at 1, 7, and 28 days. The second phase was conducted to investigate the water resistance of the developed gypsum steel slag mixture. The third phase was conducted to study the effect of addition of rice husk with different weight ratio (0, 5, 10, 15, 20, 25 %) to the highest strength of gypsum steel slag mixture, which optioned from last phases. Compressive strength, flexural strength, water absorption and density of the gypsum steel slag - rice husk mixtures were determined and investigated.

The results showed the highest compressive strength and water resisted for gypsum slag mixture that was at slag percent of 30%. Also, compressive strength and density of gypsum steel slag rice mixture were reduced by increasing the rice husk content. The best rice husk content was 15 % to enhance the flexural properties of steel slag - rice husk-gypsum mixture binder.

Keywords: *Gypsum, Steel lag, Rice husk, Engineering characteristics.*

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1. INTRODUCTION

Construction materials cause a lot of environmental problems in the fabrication process such as cement. It is emits about one ton of CO_2 into the air per each ton of cement. It is important to produce environmental friendly construction materials, which are structurally safe and durable. Gypsum is one of the most environmentally friendly binders, because the energy consumption for its production is substantially lower compared to the cement or lime and it can be also produced from many industrial waste products. It is also recyclable. Also, the friendly construction products depend on the use of alternative products as industrial wastes conventionally called green materials.

Gypsum binder which is also known as calcium sulfate semihydrate ($CaSO_4$-0.5 H_2O) is used in construction industry as a finishing material due to its ease of use, fire resistant, and environmentally friendly (Khalil et al 2018 and Zhu et al. 2018).

Also, gypsum binder has some limitations such as brittleness and low water resistance of its matrix that make it suitable for the interiors of buildings, and not for external applications (external plastering). (Weyeret al. 2015 and Henry et al. 2011).

Gypsum composite disadvantage can be improved by adding filler materials. Composite filler can be either organic or inorganic depending on the needed properties for the end product. Several researchers have reported the additions of some industrial and agricultural by-products, as a filler, to gypsum matrix to improve the water resistance properties, and the mechanical characteristics of gypsum-based composites (Sagnak 2018 and Riveraet al. 2012).

Riveraet al. (2012) reported that water resistance of gypsum composite increases by adding Portland cement or ground granulated blast furnace slag and the active mineral additives comprise amorphous silica. These additives lead to the formation of a dense, fine-crystalline structure of gypsum anhydrous matrix with finely dispersed amorphous new formations and improve the physical and mechanical properties of the binder.

The best results to obtain water resistant gypsum composite materials were achieved by the use of the composed binders with latent hydraulic and pozzolan materials (like ground granulated blast furnace slag, fly ash, and rice husk ash). Because pozzolan reaction needs the alkaline environment and gypsum is neutral or slightly acid, these binders have to contain some alkaline component (usually hydrated lime or cement). Such arterials are called ternary, because three main components create the binder (Pervyshin et al 2017).

Hekal et al. 2012 reported that steel slag is a by-product of the steel making process and has a complex chemical structure, consisting mostly of oxides and silicates that are formed as a result of the oxidation of various additives within the steel. Other slag products, such as blast furnace slag, coal slag, copper slag, etc, have been successfully utilized in civil construction works or producing abrasive materials and cements.

On the other hand, gypsum composite mechanical properties can be improved by using inorganic and organic fiber fillers. Polypropylene fibers are an example of inorganic fiber materials while the natural based materials such as natural fibers are the example of organic based fillers (Henry et al. 2011 and Selamat et al. 2019). Agricultural waste like waste paper, wheat straw, barley straw, rice straw, rice husk, cotton, flax, and oil palm trunk have been used as fillers to improve flexural and compressive strength of gypsum composites. It was given that agricultural waste fibers have higher tensile strength, less abrasiveness and lower cost compared to the inorganic reinforce material types of fillers (Abuh&Umoh 2015, Ramesh et al. 2017, Hospodarova et al. 2018, Ashori 2017, and Selamat et al. 2019).

Saraswathy and Song (2007) reported that lot of researches have used rice husk as a rough material in industrialization as in civil engineering field, which has been widely used as additive to cement mixture due to beneficial pozzolanic effect.

Kim (2009) reported that rice husk and cork addition are good reinforcement materials for the production of the gypsum rice husk board and to obtain high insulation gypsum building material. The gypsum-rice husk board modulus of rupture and the modulus of elasticity increased as rice husk contents increased until 30 %. The rice husk gypsum boards are suitable for use as an interior ceilings and walls.

This study is aiming to evaluate the physical potential of incorporating different percentages of steel slag in the production of gypsum-based composite by investigating its effect on compressive strength, density, porosity and water resistance. Also, Rice husk is incorporated with gypsum steel slag composite to produce porous material for geotechnical engineering application where excellent drainage ability and lightweight characteristics are essential.

2. MATERIALS AND METHODS

This work was carried out to develop a green composite, eco-friendly material of gypsum with steel slag and rice husk.

2-1 Materials:

The materials used for this experiment are locally available, which illustrated as follow:

1- Gypsum was used as the base binder material. The main component of gypsum is 95% Calcium sulfate semihydrate ($CaSO_4 . 0.5 H_2O$). The gypsum was obtained from Sinai Gypsum Factory.

2- Steel slag is a steel production by-product, which is produced in the separation of the impurities from molten steel. The slag is a molten liquid consists of silicates and oxides solution, which solidifies upon cooling as shown in Fig. (1). The steel slag was obtained from Helwan Steel factory in Helwan City. The chemical composition ofgypsumandsteel slag were measured by X-ray fluorescence technique at the Faculty of Science laboratory, Alexandria University. The results are presented in Table (1).

Table 1: Constituent composition of steel slag and gypsum, %.

Constituent composition,%	Fe_2O_3	SiO_2	CaO	Al_2O_3	MgO	SO_3	Na_2O	Traces
Gypsum	0.04	0.23	32.7	0.09	0.42	43.68	0.03	22.81
Steel Slag	28.14	11.41	41.27	1.62	8.24	0.41	0.03	8.88

3- Rice husk was obtained from Rice Research and Training Center, Alexandria as shown in Fig. (2).

4- A clean tap water was used during this experiment.

2-2 Work plan:

The experiments were conducted into three groups as follows:

1- The first group was conducted to investigate the effect of replacing gypsum by steel slag waste of (0, 10, 20, 30, 40 and 50%) on the compressive strength of steel slag gypsum mixture after curing times of 1, 7 and 28 day as given in Table (2).

Fig. (1). Steel slag sample.Fig. (2). Rice husk sample.

2- The second group was conducted to investigate the effect of immersion time of 1, 7 and 28 day in water on the compressive strength of the above mention gypsum – steel slag mixes.

Table 2: Mixture proportions of Gypsum - Slag binder, by weight.

Mix.	Gypsum, g	Steel slag, g	Water content, g
G100 S0	1000	0	600
G90 S10	900	100	600
G80 S20	800	200	600
G70 S30	700	300	600
G60 S40	600	400	600
G50 S50	500	500	600

3- The third group was conducted to investigate the effect of mixing rice husk with the best percentage of gypsum steel slag mixture which showed the highest compressive stress, based on the results obtained from the first and second group experiments. The percents of rice husk were (0, 10, 15, 20 and 25%) of the total weight of gypsum- steel slag mixture as shown in table (3).

2.3 Methodology:

2.3.1 Preparation of Gypsum- Steel slag mixtures:

Test specimens were prepared as follows:

A- The materials used for each mixture as given in tables (2) were weighed and mixed in dry condition for 3-4 minutes.

B- Water was added to the blender for improving the workability of mixing process.

C- Mixing process was continued for about 2 minutes. The obtained mixtures were poured in a (40 ×40 × 160 mm) mold as shown in Fig. (3). Molds were completely covered with plastic sheets to avoid any loss of water evaporation.

D- Specimens were left at room temperature for the first 24 hours.

E- The specimens were removed from their moulds, after the 24 hours period.

F-The specimens of each mixture were divided into two groups, the first group was used to measure the compressive strength of dry mixture after 1, 7 and 28 days, while the second group was left to cure at room condition in plastic bags for 27 days. After that, the second group specimens were soaked in water for 28 days. Compressive strength of soaked specimens were determined after soaking for 1, 7 and 28 days from soaking.

Table 3: Proportions of gypsum –steel slag - rice husk mixture, by weight.

Mix.	Gypsum- steel slag, g	Rice husk,g	Water, g
G1	1000	0	600
G2	950	50	610
G3	900	100	630
G4	850	150	650
G5	800	200	670
G6	750	250	700

2.3.2 Preparation of Rice Husk - Gypsum- Steel slag mixtures:

The preparation of test specimens was done following the same steps in the preparation of gypsum- steel slag mixtures. Rice husk percentages of 0, 5, 10, 15, 20 and 25% by weigh were added to the heights strength gypsum- steel slag mixture as given in table (3).

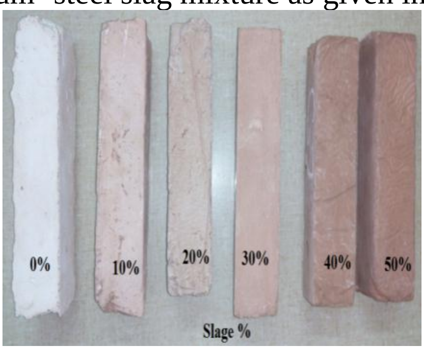

Fig. (3). Casted presumes samples of Gypsum - Slag binder.

Fig. (4). Casted presume sample of Slag - Rice husk- Gypsum binder.

2.4. Mechanical tests

2.4.1 Compressive strength (CS)

The compressive strength of the gypsum binder was tested according to European Standard (DIN EN 196-1). A servo hydraulic material testing system with a maximum capacity of 100kN was used to apply a constant loading rate test of 13.72 MPa per min until failure. The testing machine was located in the lab of testing materials, Faculty of Engineering, Alexandria University. A cubic specimen of 40 mm dimension was used for each test. Three replicates of compressive strength tests were applied on specimens. The compressive strength (CS) was calculated as follows:

$$CS = \frac{Fu}{W^2} \quad \text{...(1)}$$

Where:

CS: Compression stress, MPa. Fu: Failure load, N.

W: Width of sample, mm.

2.4.2 Flexural strength (FS)

The flexural strength of the gypsum binder was carried out by the European standard (DIN EN 196-1) using a Universal Testing Machine. Beams of dimensions 40 × 40 × 160 mm were cast and then subjected to the three point Flexural test. Maximum load was measured to calculate Flexural strength after 28 days using the following formula for three point bending test:

$$FS = \frac{3PL}{2BD^2} \quad \text{...(2)}$$

Where:

FS: Flexural strength, MPa. P: Maximum load, N.

L: Length of sample, mm. B: Width of sample, mm.

D: Thickness of sample, mm.

2.4.3. Softening index for gypsum mixture (SSI)

The softening index (SSI) for gypsum mixture was calculated to determine the effect of immersion time in water of gypsum binderon compression stress according to compression stress of dry sample.

The softening index for gypsum binder was calculated as follows:

$$SSI = \frac{Csw}{Csd} \times 100 \quad ....(3)$$

Where:

SSI: Softening index for gypsum binder, %.

Csw: Compression stress for immersed gypsum binder in water, MPa.

Csd: Compression stress for dry gypsum binder, MPa.

5.2. Physical properties

5.2.1. Bulk density

For determination of hardened composite bulk density, a set of samples, each of dimensions 4×4×16 cm were tested. Three replicates of each sample were tested after 28 days of removing from the mold. All samples were dried at 105 ± 5ºC until a constant weight was achieved and then were placed in the air to cool down.

The weight and the volume based on the three basic dimensions of each dried specimen were measured. The bulk density was determined as follows:

$$\rho_b = \frac{\mathbf{W_d}}{\mathbf{V}} \quad ....(4)$$

Where:

$\boldsymbol{\rho_b}$: Bulk density of the sample, g/cm^3. **W_d** : Weight of dry sample, g.

V : Volume of the sample, cm^3.

2.5.2. Water absorption test

Three replicates were used for each test after 28 days. All samples were dried at 105±5ºC until a constant weight was achieved. Water absorption was determined according to the American Standard Testing Method ASTM (D-1037) as follows: the dried specimens were weighed to the nearest 0.01 gram. The tested specimens were then soaked in water at room temperature for 24 hours. The specimens were hanged to drain the water for 10 minutes and the excess surface water was wiped. The specimen was weighed to the nearest 0.01 gram. The amount of water absorbed after 24 hours of soaking was calculated as a percentage of the original weight of test specimens.

$$W = \left(\frac{W_a - W_d}{W_d}\right) \times 100 \quad ....(5)$$

Where:

W : Water absorption, %.   Wa : Weight of saturated sample in air, g.
Wd : Specimen dry weight, g.

3. RESULTS AND DISCUSSION

3.1 Effect of replacing gypsum by steel slag

3.1.1 Compressive strength (CS)of gypsum steel slag mixtures .

The effect of replacing gypsum by steel slag waste of (0, 10, 20, 30, 40 and 50%) on the compressive strength of mixture binder after curing time of 1, 7 and 28 day are shown in Fig.(5) and table. (4).

In general, the results showed that, the compressive strength (CS) for all tested hardened gypsum binder increases with the increase of slag from 0 to 30%, while resulted in decreases compressive strength from ٣٠ to ٥٠%. The maximum values of compressive strength were 1.77, 4.33 and 6.86 MPa for curing times of 1, 7 and 28 day respectively at steel slag of 30%, while the minimum values were 0.98, 2.25 and 3.23 MPa for curing times of 1, 7 and 28 days respectively at steel slag of 50%.

A continuous increase in the compressive strength with curing time is due to the reduction of the porosity and the increase of the density of microstructure in gypsum binder by increase hydrating time. The best slag percent is 30% to make the highest compressive strength for steel slag gypsum binder.

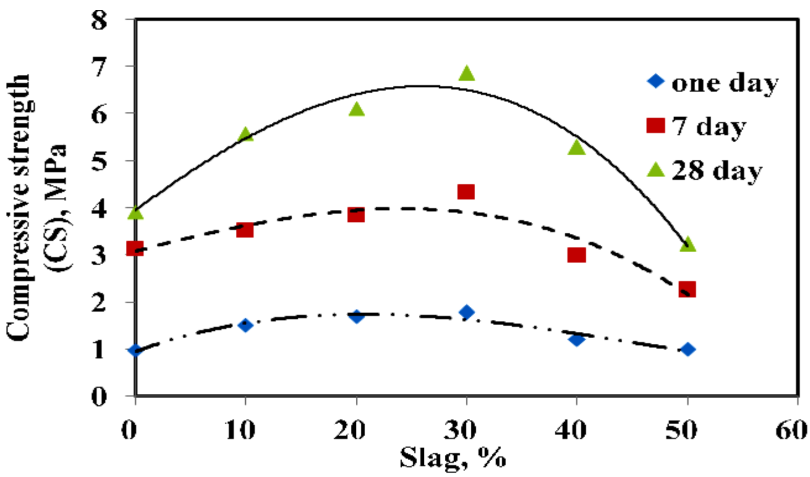

Fig. (5). Effect of slag, % on compressive strength of gypsum binder.

Table. (4). Effect of slag, % on compressive strength of gypsum binder.

Experiment	Gypsum, %	Slag, %	Compressive strength, Mpa		
			24 hr	Curing time 7 day	28 day
T1	100	0	0.98	3.14	3.92
T2	90	10	1.52	3.53	5.59
T3	80	20	1.70	3.84	6.11
T4	70	30	1.78	4.33	6.86
T5	60	40	1.21	2.99	5.30
T6	50	50	1.00	2.27	3.24

3.1.2 Effect of immersion time in water on the compressive strength of gypsum steel slag mixtures .

The effect of immersion time of (1, 7 and 28 day) in water on the compressive strength of gypsum steel slag hardened mixtures for steel slag percentages of (0, 10, 20, 30, 40 and 50%) are presented in Table (5) and Fig (6).In general the results showed that, the compressive strength for all tested gypsum binder increased with the increase of slag from 0 to 30%, and resulted in decreases in compressive strength **(CS)** beyond 30 to 50 % steel slag. The maximum values of compressive strength (CS) were 6.86, 6.77 and 6.7 MPa at immersion time of 1, 7 and 28 day respectively for steel slag of 30%. The minimum values of compressive strength were 3.25, 2.38 and 1.84 MPa at immersion time of 1, 7 and 28 day respectively for steel slag of zero %.

Below 30% slag, the highest compressive strength is the dry, while above 30% slag, the dry is the lowest.

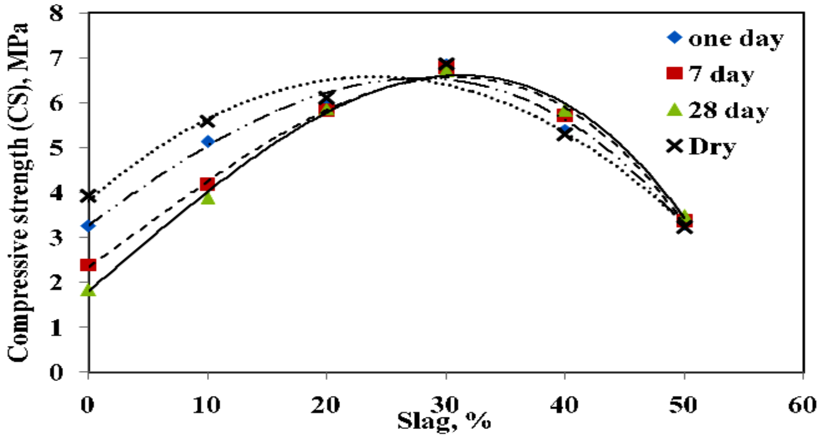

Fig. (6). Effect of immersion time on compressive strength of gypsum hardened binder.

It was observed that all compressive strength values for different immersion times were converge at steel slag higher than 30% for gypsum hardened mixture. This may be due to increase of sample moisture resistanc by using steel slag higher than 30%. The best slag percent is 30 % to make water resisted slag gypsum binder.

Table. (5). Effect of immersion time on compressive strength of gypsum hardened mixture.

Gypsum, %	Slag, %	Compressive strength, Mpa			
		Dry	Immersion time in water		
		28 day	24 hr	7 day	28 day
100	0	3.92	3.26	2.38	1.84
90	10	5.59	5.13	4.18	3.88
80	20	6.11	5.96	5.83	5.86
70	30	6.86	6.86	6.78	6.71
60	40	5.30	5.40	5.71	5.83
50	50	3.24	3.30	3.37	3.48

3.1.3. Effect of immersion time on the softening index of gypsum mixtures.

The effect of immersion time for 1, 7 and 28 days on softening index (SSI) of gypsum binder for slag percentages of (0, 10, 20, 30, 40 and 50%) are shown in Fig (7).

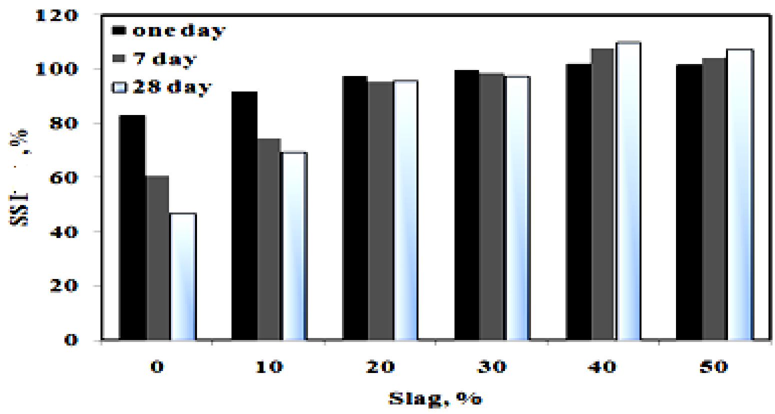

Fig. (7). Effect of immersion time on the softening index of gypsum mixtures.

In general, the results showed that, the SSI for all tested gypsum binder increases with the increase of slag from 0 to 50%. It was observed that there are differences between SSI values at slag percentages of (0, 10 and 20%), while were the same at slag percentages of (30, 40 and 50) for all immersion times. This is due to the increase in the sample moisture resists by using steel slag higher than 30%.

3.2 Effect of gypsum-steel slag binder with rice husk

3.2.1 compressive strength and the flexural strength

The effect of mixing rice husk of (0, 5, 10, 15, 20 and 25%.) to gypsum steel slag of 30% on the compressive strength and the flexural strength of gypsum hardened binder after 28 day are presented in Fig (8).

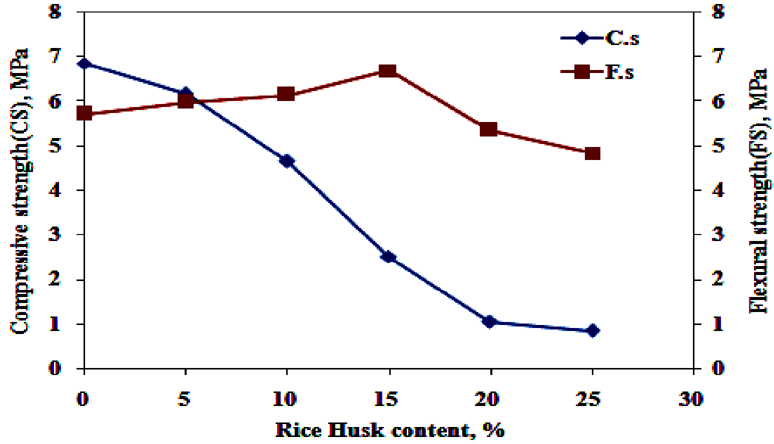

Fig. (8). Effect of rice husk, % on the compressive strength and the flexural strength of steel slag gypsum binder after 28 day.

In general, results showed that, the compressive strength for all tested hardened gypsum mixture decrease with the increase of rice husk content. The maximum value of compressive strength was 6.86 MPa for rice husk 0 %, while the minimum value was 0.84 MPa for rice husk of 25%.When 25% rice husk is added into the specimen mixture, the compressive strength is only 12% of the control sample, which is due to the porous nature of rice husk. The presence of higher amounts of rice husk changes the microstructure of gypsum mixture resulting in the production of low strength porous material. Also, rice husk absorbs a lot of water and this reduces the degree of compaction of the fresh mix resulting in presents of void and non-uniform distribution of rice husk. This condition explains the reduction of compressive strength with introduction of rice husk. On the other hand, The flexural strength for all tested hardened mixtures increases with the increase of rice husk from 0 to 15%, while resulted in decreases flexural strength from 15 to 25% rice husk. The maximum value of flexural strength was 6.68 MPa for rice husk 15%, while the minimum value was 4.83 MPa for rice husk of 25%.When 15% rice husk is added into the specimen mixture, the flexural strength is improved by

17 % of the control sample. The best rice husk content toenhance the flexural properties of gypsum-steel slag mixtures is up to 15 %.

3.2.2 Bulk density and water absorption:

The effect of adding rice husk (0, 5, 10, 15, 20 and 25 %.) to gypsum-steel slag mixture on the density and the water absorption are presented in Fig (9). In general, the results showed that, increasing rice husk from 0 to 25% for all tested hardened mixtures resulting in decreasing density.Since rice husk possess lower density compared to the other particle, the density of gypsum steel slag rice husk mixtures decreased with the increase of percentage of rice husk content. On the other hand, the addition of rice husk will cause increment in void and thus lower the density of the sample. The density of gypsum steel slag rice husk mixtures in this investigation ranges from 1.73 g/cm^3 at 0 %rice husk content to 0.93 g/cm^3 at 25% rice husk content. The lowest density is given for 25% rice husk sample which is about 46% of the control sample. These results of density indicate that the gypsum steel slag rice husk mixture have a great potential to be applied in geotechnical field as lightweight material in order to minimize surcharge to the ground and also reducing the lateral pressure as lightweight backfill.

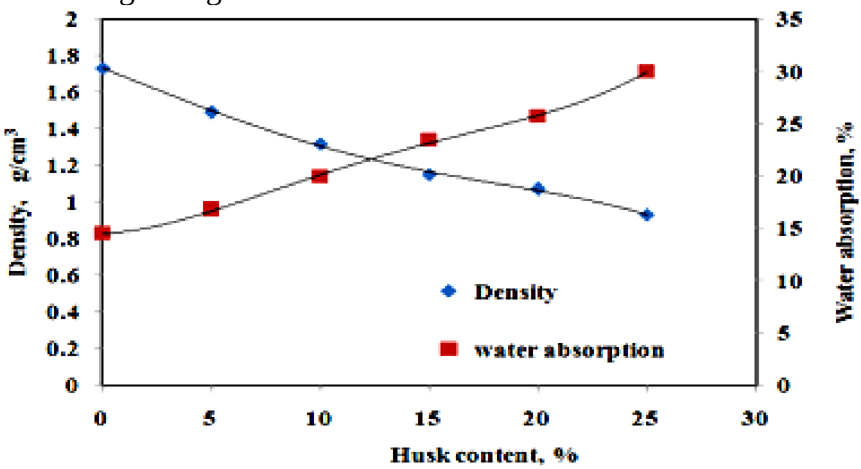

Fig. (9). Effect of rice husk, % on the bulk density and water absorption of gypsum hardened binder after 28 day.

The degree of water absorption of mixture which contain rice husk is presented in Fig. 9. Comparing all the gypsum steel slag rice husk mixture to the control sample, it can be observed that the water absorption of rice husk mixtures increases with the amount of rice husk added into the mixture. The maximum value of water absorption was 30% at rice husk of 25%, while the minimum value was 14.5 % at rice husk of 0%. Compared to the control sample, the increment of water absorption by 25% rice husk content is very high which is two times higher than that of control sample. In general, All gypsum steel rice husk mixtures show proportional relationship between density, compressive strength and water absorption.

4. CONCLUSIONS

This investigation was carried out to develop a composite from gypsum steel slag, and rice husk to make Eco-Friendly composite. Test results show that:

- The compressive strength for all tested hardened gypsum steel slag mixture increases with the increase of slag from 0 to 30%, while resulted in decreasing compressive strength from 30 to 50% steel slag.
- The maximum value of compressive strength was 7 MPa at curing time of 28 day for mixture contains steel slag of 30%, while the minimum value was 1MPa at curing time of one day at steel slag of 50%.
- Water resistance of gypsum matrix improved when steel slag content ranged from 30% to 50%.
- Incorporating rice husk in gypsum steel slag mixtures decreasing compressive strength and density of the composite.
- The highest flexural strength of gypsum steel slag rice husk composite was observed up to 15 % rice husk.
- Water absorption of gypsum steel slag rice husk composite increased by increasing husk content.

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الملخص العربي

الخصائص الهندسيه لماده مركبه صديقة البيئة مصنوعة من الجبس و خبث الحديد و سرسه الأرز

د/محمد إبراهيم نصر مرسي[١] د/ هيثـم حسين يوسف محمد[٢]

تهدف هذه الدراسه الي معالجه خبث الحديد الناتج من صناعه الحديد و سرسه الارز كاحد اهم المخلفات الزراعية بمصر لانتاج مواد بناء صديقة للبيئة لاستخدامها في تطبيقات المنشات الزراعية.

تم تنفيذ التجارب علي ثلاث مراحل:

- المرحلة الأولى: دراسه تأثير إحلال الجبس بخبث الحديد بنسب وزنيه مختلفة (صفر ، ١٠، ٢٠ ، ٣٠، ٤٠ ، ٥٠٪)على إجهاد الضغط عند فترات زمنيه ١ ، ٧ ، ٢٨ يوم .
- المرحله الثانية: دراسة تأثير الغمر في الماء علي إجهاد الضغط لخلط لجبس وخبث الحديد.
- المرحلة الثالثة: دراسة تأثير إضافة سرسه الأرز بنسب وزنيه مختلفة (صفر ، ٥ ، ١٠ ، ١٥ ، ٢٠ ، ٢٥٪) علي الخصائص الهندسية إلى أفضل خليط تم الحصول عليه من التجربتين السابقتين.

تم دراسه الخصائص الهندسية (إجهاد الضغط و إجهاد الانحناء و معدل امتصاص الماء وكثافة خليط الجبس و خبث الحديد والسرسه الارز) عند فترات زمنية مختلفه.

و أظهرت النتائج ما يلي :

- أن أعلي قيمة لإجهاد الضغط كانت ٧ ميجا بسكال عند ٢٨ يومًا (للخليط المكون من ٣٠٪ خبث حديد و ٧٠% جبس) ، بينما كانت أقل قيمة لإجهاد الضغط ١ ميجا بسكال عند يوم واحد (للخليط المكون من ٥٠٪ خبث حديد و ٥٠% جبس).
- تحسنت مقاومه خليط الجبس وخبث الحديد للماء للخلطات التي تحتوي علي نسب خبث حديد بين ٣٠% و ٥٠%. وذلك عند فترات الغمر في الماء من يوم حتى ٢٨ يوم.
- إضافة سرسة الأرز إلي خليط الجبس وخبث الحديد بنسب وزنيه تتراوح بين صفر إلى ٢٥٪ أدت الي انخفاض مقاومة الضغط من ٧ ميجا بسكال الي ٠,٨٦ ميجابسكال علي الترتيب
- أظهرت النتائج تحسن اجهاد الانحناء لخليط الجبس وخبث الحديد بزيادة محتوي سرسه الارز حتي ١٥% بالوزن
- حدث انخفاض لكثافة خليط الجبس و خبث الحديد من ١,٨ طن/ متر^{٣} الي ١ طن/ متر^{٣} بزيادة محتوي سرسة الارز من صفر الي ٢٥ % بالوزن.
- بزيادة محتوي سرسة الارز من صفر الي ٢٥ % بالوزن لخليط الجبس و خبث الحديد ازداد معدل تشرب الماء من ١٣% الي ٣٠%.

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