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Compressive Strength of Mortar with Partial Replacement of Cement by Fly Ash and GGBFS.

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ABSTRACT

The compressive strength characteristics of mortar containing Ground Granulated Blast Furnace Slag (GGBFS) and Fly Ash (FA) in mortar by partial substitution of cement are investigated in this work. The increased demand for cement in the construction industry is a concern for environmental degradation; in this case, waste materials such as GGBFS and FA are used to replace cement. The optimal level of GGBFS and FA was determined using a percentage range of 0% to 40% for different curing days. Compressive strength tests were performed on the replaced mortar. For all mixes, the binder-to-water ratio was kept at 0.4. The compressive strength tests were conducted for 7, 28 and 90 days of curing on a Mortar. The result obtained that as the curing time increased the compressive strength of mortar containing GGBFS and FA increased. In comparison to M1 (cement only), the compressive strength improved by 13.15 percent and 15.5 percent at M3 (20%FA) and M8 (30%GGBFS), respectively. The results showed that adding GGBFS and FA to mortar improve compressive strength, which is improves the mechanical properties of the mortar.

1. Introduction

The growth of non-degradable waste products, along with an expanding consumer population, has resulted in a waste disposal challenge, creating an economic and environmental issue. Today's wastes will last hundreds, if not thousands, of years in the environment. Environmental difficulties such as air, surface, and ground water contamination, as well as economic ones like as landfilling maintenance costs, are particularly significant for both wastes. This rapidly growing waste stream is a major environmental concern that must be addressed in a cost-effective and environmentally sustainable manner. One solution to this crisis is to recycle waste into useful products to replace natural/commercial products whenever possible, which will reduce the economic and environmental issues associated with waste disposal while also reducing natural resource depletion.

The exothermic reaction between cement and water can be reduce by replacing the Portland Cement (PC) with FA [1]. Partially substituting PC with FA results in a longer-term heat release due to the slower pozzolanic reaction. As a result, the temperature of concrete remains lower since heat is lost as itis generated [2]. The FA contribution to early age heat generation is estimated to be between 15 % and 30% of that of the same amount of PC [3]. While most low calcium Class F of FAs will decrease the temperature rate increase when used in concrete as a replacement for PC, high calcium Class C of FAs may not necessarily decrease heat evolution due to their self-cementitious capabilities [2]. Heat evolution rate, in general,

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is equal to the rate of strength growth. For ashes with high calcium react with water very quickly, creating excessive heat rather than lowering the hydration heat [3]. The heat generation rate by hydration and pozzolanic processes, the size of the concrete member and of loss rate in heat and the thermal characteristics of the concrete and environment all influence temperature rise in concrete [2]. Huge sections can be cast with a maximum temperature exceeding of 40 oC due to the significant reduction in maximum temperature. [1].

The major problem of using high volume of FA concrete is slower early strength generation due to less cementitious properties [4]. Low heat generation can affect the timely formwork removal process. As the hydration reaction remains really slow due less embodied energy. Specialized approach like heat insulation during construction should be taken into consideration. On the other hand, high volume FA and/or slag modified concrete shows reduce internal temperature and improved workability [5].

The properties of the FA (chemical composition, reactivity, properties and particle size), the cement, the concrete components properties, the curing conditions, the temperature and the presence of other additives all have an impact on the strength during the specified age and the strength gain rate of FA concrete [3,6,7]. Although FA-containing concrete mixes tend to increase strength at a lesser rate than non-FA-containing concrete, long-term strength is bigger in general [1].

If the concrete is kept wet, the continuing pozzolanic action of FA offers strength growth at later ages when the rate of strength development of hydraulic cement declines. As a result, if concrete is cured or it's exposed to adequate amounts of moisture throughout its service life, concrete containing FA with same or lower compressive strength at early ages may have the same or more compressive strength at late age than the concrete without FA. With time, the strength gain will continue, resulting in higher later-age compressive strength than can be produced by adding more [3,7].

Despite its slower rate of strength growth at an early age, Class F ashes will contribute in the improvement of long-term compressive strength in concrete than ashes of Class C The incorporation of FA hydration products in concrete results in an increase in strength development during curing as a consequence of the ongoing process of pore refining [2]. Because of the increased activation energy necessary for pozzolanic processes, elevated temperature curing is particularly helpful to early compressive strength and future compressive strength improvement of FA concrete [7].

Within the industry, there is worry that the poor early strength of high-volume FA and/or slag modified concrete might be an issue. However, several research have been undertaken on this topic, with favorable results. According to Siddique [8], replacing cement with present of 40, 45 and 50 FA content decreases concrete strength at 28 days; however, there is a sustained and considerable development in compressive strength after 28 days in comparison to standard PC concrete.

GGBFS is a by-product of steel and iron production [16, 17, and 18]. Its chemical makeup varies a lot depending on the raw materials used to make iron. The use of GGBFS as a partial cement might minimize CO2 emissions, reduce GGBFS waste, and the building industry's dependence on cement as the only binder. With the addition of GGBFS [19], the durability of reinforced concrete buildings is improved. Furthermore, GGBFS-containing concrete is resistant to environmental effects such as sulphate assault, chloride penetration, and alkali-silica reactive expansion, allowing for a longer corrosion-free service life [20].

This work attempted to consist of two possible industrial by-products, i.e. FA and GGBFS, into the mortar mix. The strength of the cement-mortar mix is used to determine the compatibility of FA and GGBFS. A laboratory compression tests were conducted with different binder contents of FA, GGBFS, and cement. In this work, the results of the tests are given, compared, and analyzed.

2. Materials

2.1. Cement

Throughout this study, the ordinary PC (type I) manufactured in the Iraq under the trade name

(Tassloga) was used. To avoid exposure to the elements, it has been kept in airtight plastic containers. Tables 1 and 2 shows its physical properties and chemical composition. Results of the tests show that the cement meets the requirements of Iraqi specification No. (5)-1984[14].

Table 1: Chemical oxide analysis, weight %, for cement used

Oxide	Content %	Limit of Iraq specification No. (5) _ 1984(14)
CaO	62.210	----
SiO2	20.180	----
Al2O3	5.0	----
Insoluble Residue I.R	1.110	<1.50
MgO	2.310	<5.0
SO3	1.210	< 2.80
Na2O	0.280	-----
Fe2O3	3.6	-----
K2O	0.510	-----
Loss on ignition L.O. I	2.90	<4.00

Table 2: Physical properties of the cement

Physical properties	Test result	I.Q.S. No.5, 1984(14)
Specific Surface Area (Blaine Method), cm^2/g	296.5	230 (min)
Setting Time (VicatApparatatus),	1:00	00:45 (min)
Initial Setting, (min) final setting, (hr)	5:00	10:00 (max)
Compressive strength, MPa at 3 days	18.76	≥ 15.00
Compressive strength, MPa at 7 days	26.81	≥ 21.00
Soundness (autoclave Method), %	0.35	≤ 0.8

2. 2. Pozzolanic materials

GGBFS and FA, two pozzolanic materials, were used as binding materials in the development of blended mortars. FA of F class [9] and GGBFS accordance to ASTM C 989 was employed. The chemical and physical parameters of GGBFS and FA as measured by X-ray fluorescence are summarized in Table 3. (XRF).

Table 3: Properties of FA and GGBFS.

	Fly Ash	GGBFS
Na2O (%)	0.40	0.350
SiO2 (%)	57.20	36.410
CaO (%)	2.20	34.120
Fe2O3 (%)	7.10	0.690
MgO (%)	2.40	10.260
Loss of ignition (%)	1.50	1.640
SO3 (%)	0.30	0.30
K2O (%)	3.40	0.970
Al2O3 (%)	24.40	10.390
Specific surface area (m2/kg)	379.0	418.0
Specific gravity	2.250	2.610

Figure 1. Flay ash

2.3. Super plasticizer

The plasticizer is used to develop the mortar workability with adding the water, and it is used as 5 percent of the binder. It is a polycarboxylic ether based high range water reduction superplasticizer. This superplasticiser is a liquid that meets with the ASTM C494-2005. The major features of superplasticizer SP1 are shown in Table 4.

Table 4: Properties of super plasticizer (SP1) *

Property	Description
Chloride content	< 0.10%
Air entrainment	Maximum 1.0%
Colour	Dark brown / black liquid
Freezing point	0.0%
Alkaline content	< 3.0%
Specific gravity	1.070 at 25^0C

* According to manufacturer

Figure 2. Super plasticizer

2.4 Tap water

The water utilized in the mortar mix design and curing is potable water supply from water supply system. It is free from organic compounds or suspended solids.

2.5 Fine aggregate

Throughout this work natural sand from (Al-Soddor source) is used as fine aggregate. Tests were conducted to assess the gradation and specific gravity. The results demonstrate that the sulfate content and grading meet the standards of the Iraqi Standard IQS 45-1984, and the specific gravity was 2.6.

Figure 3. Fine Aggregate

3. Mix proportion

The purpose of a mortar mix design is to have economic mix proportions for the available mortaring materials which complies with the required has adequate workability to be placed in meld. Nine mixtures are prepared for eight percentages of FA and GGBFS used in this study. The first mixture used cement only. The other mixtures were prepared in replacement cement by (10, 20, 30, and 40) % of FA and GGBFS. Many trail mixes are adopted to check the workability. Table 5 gives the details of all mixes used in this study.

Table 5: Mortar mix designs

No. of mix	Cement (kg/m^3)	Sand (kg/m^3)	FA content (kg/m^3)	GGBFs content (kg/m^3)	Water (kg/m^3)	s.p. (kg/m^3)
M1	500	1631	0	0	200	25
M2	450	1614.5	50	0	200	25
M3	400	1598	100	0	200	25
M4	350	1622	150	0	200	25
M5	300	1614.5	200	0	200	25
M6	450	1622.5	0	50	200	25
M7	400	1614.1	0	100	200	25
M8	350	1605.1	0	150	200	25
M9	300	1596.6	0	200	200	25

4. Preparation of fresh mortar, casting and curing

A total of nine mixtures were made by varying the percentages of FA and GGBFS blended with cement. For about 2 minutes, the binder and aggregate were mixed together in a rotary mixer. Water was then added, and the mixing process was repeated for another 5 minutes to produce the fresh mortar shown in Figures 4 and 5.

Figure 4. Mixer used for manufacturing mortar

The fresh mortar was compacted and the excess mortar was removed. To prevent water evaporation, the molds were wrapped in plastic film. The strength of each mortar mixture was determined by casting nine (50x50x50) mm cube specimens.

Figure 5. Preparation of mortar and casting

5. Testing

5.1 Compressive strength

Compressive strength of the mortar was tested using cubes with 50 X 50 X 50 mm on a hydraulic testing machine and according to ASTM C39 (2012). The test was performed on test specimens aged 7, 28, and 90 days. After the specimen has been cured in water for the appropriate amount of time, it is tested in the compressive strength machine, as shown in Figure 6. For greater accuracy, compressive strength tests are often done on three specimens, with the average value used as the final result.

Figure 6. Mortar cube compressive strength test

6. Result and discussion

The most important property of mortar is its compressive strength. In table (6) and Figures (7, 8, 9, and10) the mortar with different cement replacement is compared with the control mortar samples up to 90 days.

The compressive strength of mortar contained GGBFS and FA were found at 7 days, 28 days, and 90 days. Figure 10 listed test results of compressive strength achieved by the adding of different partial percentage of GGBFS and FA on 10%, 20%, 30% and 40%. The results showed that at an early age (7days), the highest strength of mortar results with OPC only (32.2 MPa) and increased of the compressive strength with time reasonably with all partial replacement, the compressive strength at 90 days increased with all partial replacement in comparison to the mixture M1. This is due to the fact that there are mainly two reasons for improvement of GGBFS and FA strength. The first reason is the slag content is higher, which causes higher compressive strength, and the second reason is formation of gel, which growths with curing time and causes higher strength [10, 11]. The performance of GGBFS and FA properties with higher volume of mixes employing various material sources may vary depending on the factors of FA and GGBFS characteristics. GGBFS, on the other hand, is more likely to be constant in terms of chemical composition and physical properties. [12]. As a result, GGBFS tend to cater to more gradually uniform results. FA physical and chemical characteristics, on the other hand, are dependent on the availability of the source, and the performance of high-volume FA may vary accordingly [11].

In contrast, GGBFS has more uniform chemical and physical properties [10] and thus produces more consistent results.

The compressive strength of M2, M3, M4, M6, M7 has clearly improved as the curing days increased compared to the M1 at 90 days, as shown in Table 6. Furthermore, M8 exceeded the control mix by 15.52 percent in compressive strength. The results are compatible with those of Prince et al. [13]. As a result, it can be mentioned that 20% and 30% of FA and GGBFS are the optimal percentages for safely achieving the desired hardened of mortar while reducing the cement cost and unneeded waste recycling.

Table 6: Compresive strengh of mortar with various GGBFS and FA ratios

No. of mix	**FA %**	**GGBFS %**	**Compressive strength (MPa)**		
			7 days	**28 days**	**90 days**
M1	0	0	32.2	35	38
M2	10	0	30	34.1	39.2
M3	20	0	28.4	34	43
M4	30	0	25.8	33.7	41.6
M5	40	0	20.3	29	33.9
M6	0	10	32	35	38
M7	0	20	30	33.8	42.8
M8	0	30	31	44	43.9
M9	0	40	25	31	37.8

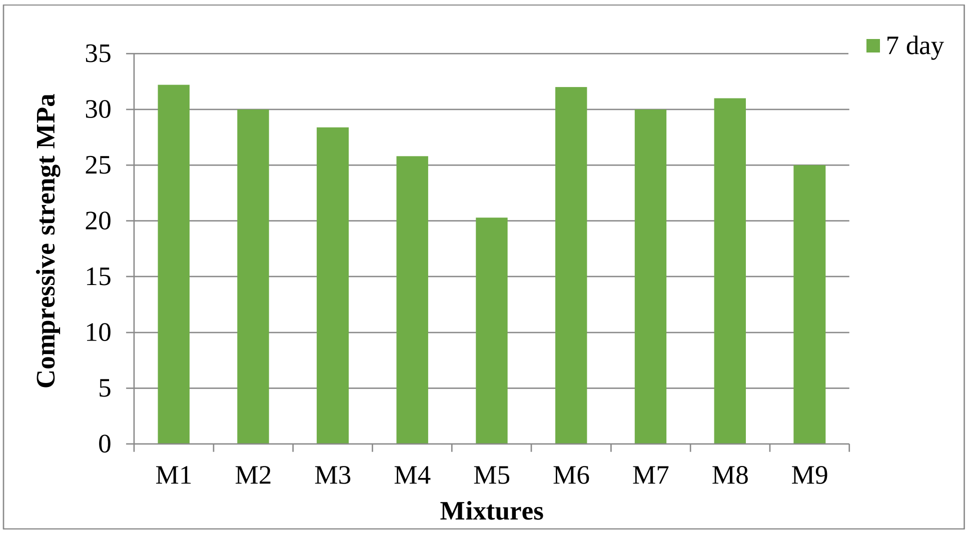

Figure 7. Compressive strengh of mortar at 7 days Various FA and GGBFS ratios

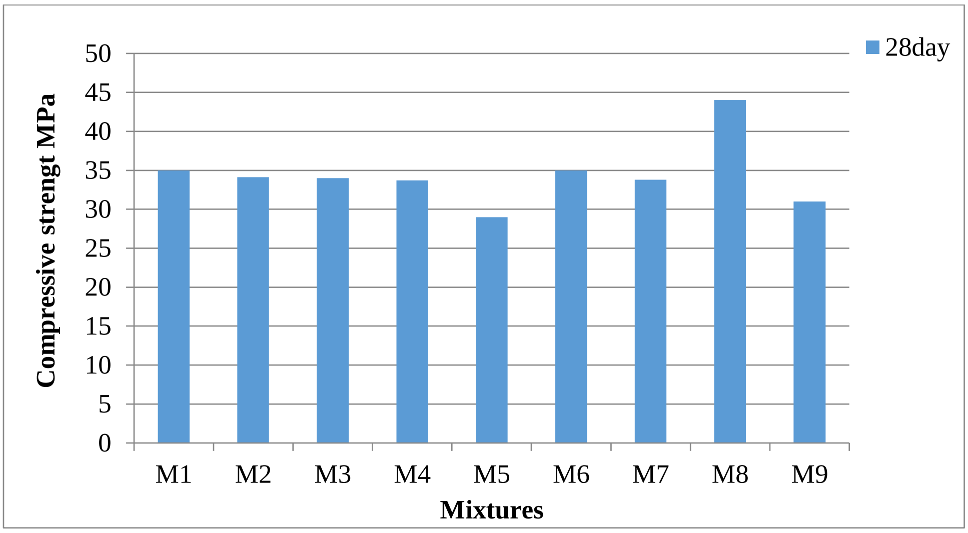

Figure 8. Compressive strengh of mortar at 28 days Various FA and GGBFS ratios

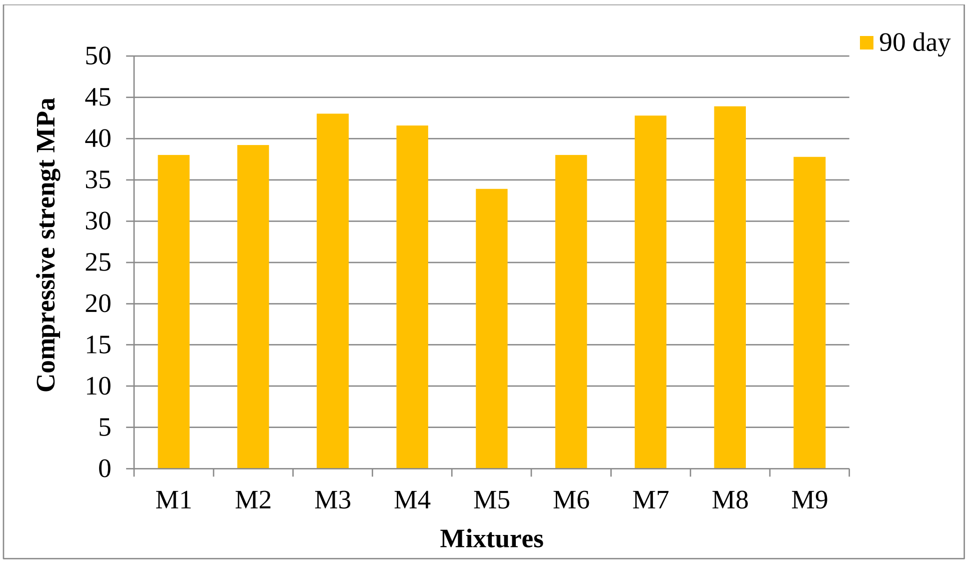

Figure 9. Compressive strengh of mortar at 90 days Various FA and GGBFS ratios

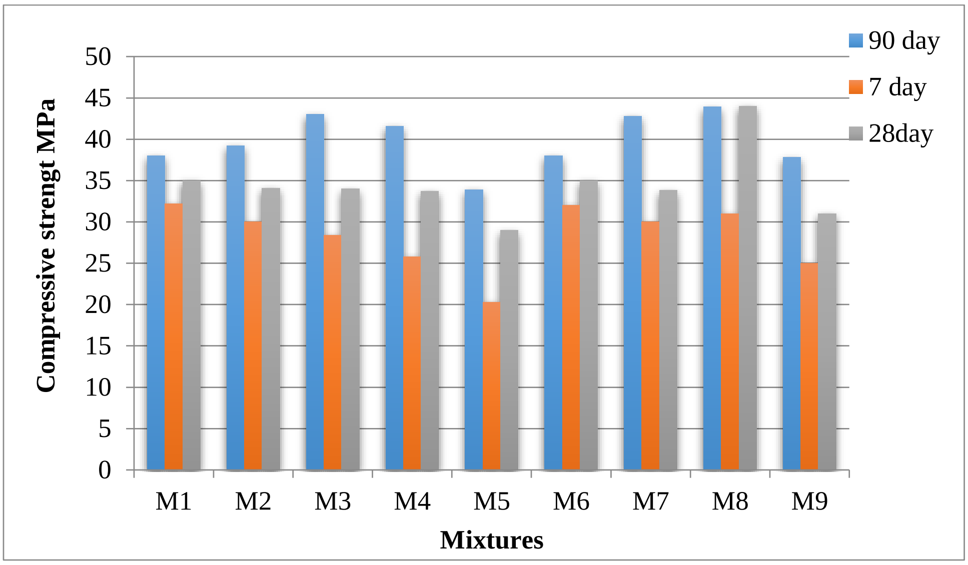

Figure 10. Compressive strengh of mortar at all ages. Various FA and GGBFS ratios

7. Conclusions

The results of a study carried out on Fly Ash and GGBFS blend with cement mortar were reported. The following conclusions are drawn from the experimental work:

1. The test results indicated that the compressive strength decreased with the increasing Fly Ash content at 7 and ages. Fly ash has an effect on early strength gain, which is most likely because the free lime is still reacting throughout the curing process.
2. The compressive strength of mortar was increased with increasing curing period.
3. At 90 days replacement 30% GGBFS and 20% Fly Ash samples obtained bigger strength than the mixture M1 with 0.0% GGBFS and further replacement of Fly Ash beyond this percentage leads to reduction in compressive strength.

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