Utilizing of slag produced from recycling of spent lead-batteries as concrete aggregate

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Using of wastes and by-products as concrete aggregate has attained great potential in the last few years. The mechanical properties of concrete fabricated by using lead slag extracted from recycling of the spent batteries in the homely workshops as fine and coarse aggregates were experimentally examined. The fine lead- slag was used as partial replacement of sand by the different percentages. Concrete mixes with different cement contents were studied. Gravel concrete mixes at the same cement contents and the same fine aggregate blends were also cast for comparison. The radiation absorption of lead- slag mortar and concrete was also studied and compared with that of ordinary concrete and mortar. Experimental results indicated that the partial replacement of sand by fine lead- slag increases the strength of concrete up to certain percentage depending on the type of coarse aggregate. Beyond this percentage, strengths decrease again till they reach a level less than that of 100 % sand mixes. The optimum replacement ratio of fine lead- slag was found to be 20 % for coarse lead- slag aggregate concrete and 40% for gravel coarse aggregate concrete. By increasing the cement content, high replacement ratios can be used without decelerating the strength below that of 100% sand mixes. Radiation absorption tests showed also a superior absorption of γ rays with the use of lead slag as concrete aggregate.

تعرض هذا البحث بالدراسة المعملية لتأثير استخدام الخبث الناتج من اعادة تدوير بطاريات الرصاص المستهلكة فى الورش الأهلية كركام للخرسانة على خواصها الميكانيكية والنفاذية الاشعاعية لها. وقد تم استخدام خبث الرصاص كركام خشن بدلاً من الزلط وكركام ناعم كإحلال جزئى للرمل بنسب مختلفة، وتمت الدراسة على خلطات خرسانية بمحتويات أسمنت مختلفة، وقورنت النتائج بنتائج الخرسانة المصنوعة من الزلط كركام خشن عند نفس محتويات الأسمنت. وتناول البحث أيضا دراسة استخدام خبث الرصاص الناعم كإحلال جزئى للرمل على الخواص الميكانيكية للمونة الأسمنتية ومقاومتها للبرى ونفاذيتها الاشعاعية. وقد أوضحت النتائج أن استخدام خبث الرصاص الناعم كإحلال جزئى للرمل يحسن من الخواص الميكانيكية لها حتى نسبة إحلال معينة ثم تقل بعد ذلك لتصل الى قيم أقل من نظيراتها ذات نسبة ١٠٠% رمل كركام ناعم عند نسبة احلال تعتمد على محتوى الاسمنت فى الخلطة. ووجد أن أفضل نسبة أحلال والتى سجلت أعلى قيمة للمقاومة هى ٢٠% للخرسانة المصنوعة من الخبث كركام خشن ،٤٠% للخرسانة المصنوعة من الزلط كركام خشن، ٥٠% للمونة الأسمنتية، وأوضحت النتائج أيضا مدى كفاءة خرسانة خبث الرصاص فى امتصاص الأشعة وخصوصا أشعة جاما.

Keywords: Recycled lead- slag, Concrete, Mechanical properties, Radiation absorption

1. Introduction

The possibility of using solid wastes as an aggregate in concrete has received increasing attention in recent years as one promising solution to the escalating solid waste problem. The use of solid wastes is not a new concept. Industrial wastes are the basis of many concrete admixtures; fly ash has been used as a pozzolanic material in concrete for several decades; blast- furnace slag has been used as both aggregate and cementitious materials [1]. From an environmental point of view, substitution of cement or natural aggregate with industrial by- products can be done in concrete production. It saves our natural resources and land. Also, it is possible to substitute concrete aggregate with by-products of metal industry, mining industry or mineral stone industry such as blast-furnace slag. In some cases when using by- products the crushing and transportation may consume more energy than in procurement of the natural resources [1]. From this point of view, cement and concrete industries can be considered to be environmentally friendly since a large amount of waste materials, such as fly ash or blast–furnace slag, can be advantageously used in manufacturing cementitious products. In other words, the use of fly ash and blast–furnace slag in cement and concrete industries is helpful for both manufacturing cementitious products with improved properties (for durability) and for reducing the disposal of waste materials [2].

The utilization of large amounts of by-products and waste materials plays a very important role in solving ecological problems. Blast-furnace slag is a by-product in the iron and steel industries and is formed by the combination of the constituent of the iron ore with the limestone flux [1]. Many research works have been conducted on the use of slag as a partial replacement of cement [2-8]. In this respect, the chemical and microscopic analysis of the Egyptian slag represented a clear interpretation for the weak performance of blast-furnace slag cement [1]. Therefore the local slag can be directed in concrete manufacture as a replacement of aggregate. When considering a waste material as concrete aggregate, three major criteria are relevant: economy, compatibility with other materials, and concrete properties [9-12]. The successful utilization of lead- slag as concrete aggregate depends on how it can satisfy the above three major considerations. The main goal of the present work is to study the possibility of using lead slag extracted from recycling of the spent batteries in the homely workshops as concrete coarse and fine aggregates. A comparison between the concrete fabricated from lead slag as coarse aggregate at different replacement of sand by fine lead slag with that of traditional gravel concrete will be invoked.

2. Materials and method

All materials used in this study were locally available materials. The cement used was type I ordinary Portland cement. The sand used was siliceous sand with 100% passing ASTM sieve No. 4. Gravel with 20 mm maximum nominal size was used as coarse aggregate. Lead- slag used in this research was supplied from recycling of the spent batteries electrodes in homely workshops. Recycled- Lead Slag (RLS) was used as both fine and coarse aggregate in concrete manufacture. The RLS was crushed to the desired gradation by using a roller mill. Sieve analysis process was carried out on the crushed RLS and the results represented by the grading curves of the fine and coarse lead-slag aggregate are illustrated in fig. 1. The results of chemical analysis of the used lead-slag are given in table 1. The physical and mechanical properties of the used fine aggregate (sand and fine lead- slag) and coarse aggregate (gravel and coarse lead- slag) are given in table 2. The coarse lead- slag were washed carefully and dried before mixing to remove any impurities and organic matters, which may weaken its bond with the cement paste. Mixing water was clean tap water free from impurities and organic matters.

Two series of mixes at cement contents of 300, 350, 400 and 500 kg/ m^3 were studied. Coarse aggregate in one of them was gravel and in the other was a coarse lead- slag particle as shown respectively in tables 3 and 4. The Total Fine Aggregates (TFA) in both series were sand partially replaced by Fine Lead Slag (FLS) particles. The percentages by volume of FLS/TFA were 0, 20%, 40%, 50%, 60% and 70% as illustrated in tables 3 and 4. All concrete mixes were of constant fine to coarse aggregates ratio of 1:2 and water to cement ratio of 0.5. A total number of 288 compression and indirect tensile test specimens were cast. Half of these specimens were prepared using natural gravel as coarse aggregate; while in the remaining specimens coarse lead- slag aggregates were used as coarse aggregate. The experimental program included also the investigation of the effect of FLS/TFA% on the compressive strength and abrasion resistance of mortar.

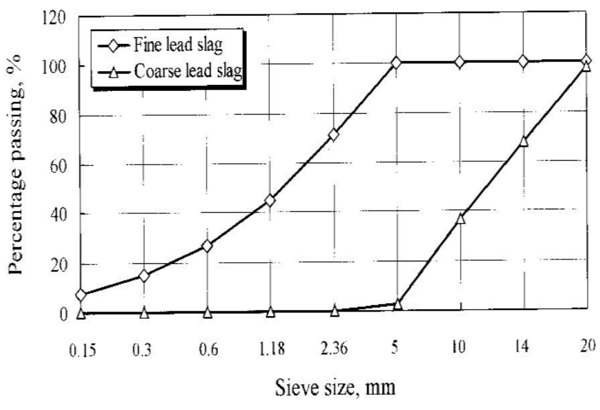

Fig. 1. Grading curves of both fine and coarse lead- slag.

Table 1
Chemical analysis of the recycled- lead slag

Constituent	SiO_2	Fe_3O_4	CaO	MgO	Na_2O	K_2O	MnO	Pb	L.O.I
(%)	12.98	72.8	2.5	0.26	0.53	0.21	0.46	4.1	3.83

Table 2
Physical and mechanical properties for the used aggregates

Property	Natural sand	Natural gravel	Fine lead-slag	Coarse lead-slag
Specific gravity	2.57	2.51	4.28	3.79
Volume weight (kg/m^3)				
Loose	1600	1530	2280	1990
Dense	1869	1640	2820	2120
% Voids				
Loose	38%	39%	47%	47%
Dense	27%	35%	34%	44%
% Water absorption	0.42	0.35	3.95	2.35
Fineness modulus	2.49	6.9	3.35	6.95
Crushing value	-	13.5%	-	29.3%
Impact value	-	6.82%	-	13.4%
Loss angeles value	-	16.7%	-	47%

Table 3
Experimental program for gravel coarse aggregate concrete

Cement content, kg/m^3	Coarse aggregate %		Fine aggregate %	
	Gravel	Lead- slag	Sand	Lead- slag
300, 350, 400, 500	100	0.0	100	0.0
			80	20
			60	40
			50	50
			40	60
			30	70

Table 4
Experimental program for lead- slag coarse aggregate concrete

Cement content, kg/m^3	Coarse aggregate		Fine aggregate	
	Gravel %	Lead- slag %	Sand %	Lead- slag %
300, 350, 400, 500	0	100	100	0.0
			80	20
			60	40
			50	50
			40	60
			30	70

Similar FLS/TFA percentages as those used in the fabrication of concrete specimens were used in mortar specimens. The mortar specimens for both compression and abrasion tests were fabricated with constant TFA to cement ratio of 3:1.

Cubes 150 mm × 150 mm × 150 mm were used for casting the concrete compression test specimens. Cylinders 150 mm diameter and 300 mm height were used for casting the splitting tensile test specimens. Dry materials were mixed first in the dry state for a time to insure the homogeneity of the mixture before adding the mixing water. Mechanical vibrator was used for compaction. Test specimens were removed from moulds one day after casting for the specimens with FLS/TFA% equals to 20% and 40% and two days after casting for the specimens with FLS/TFA% equals to 50%, 60% and 70%. The compression and tensile test specimens were cured by submerging in tap water for 28 days at room ambient temperature. Also mortar compression test specimens were cast in cubes 70.7 mm side length. Abrasion resistance test specimens were cast in cylindrical plastic moulds 25 mm diameter and 25 mm height. The mortar compression test specimens and Abrasion resistance test specimens were compacted by vibration on a standard vibrator, de-molded after 24 hours and cured at room ambient temperature in water for 7 days.

A compression-testing machine of 3000 kN maximum capacity was used for the completion of both the compression and indirect tension test for concrete. In each test the crushing load was recorded for the estimation of the compressive and indirect tensile strength. Among test methods suggested by ASTM for the estimation of the wear resistance of cementitious materials, the revolving disk (ASTM C779, Procedure A) test method [13] was selected. An aggregate abrasion testing machine (Cat. No. EL 42-500) was used to perform the test. The test specimens were exposed to abrasive standard sand, passed from 0.6 mm sieve and retained on 0.45 mm sieve, for 500 revolutions under a load of 750 gm. Each specimen was weighted before and after the test, and the weight loss was recorded.

Alfa (α), Beta (β) and Gamma (γ) rays transmission tests were carried out on both concrete and mortar specimens in order to estimate their radiation absorption. Gravel coarse aggregate concrete mix having cement content of 400 kg/m^3 and FLS/TFA% of 0% and lead slag coarse aggregate concrete at the same cement content but having FLS/TFA% of 20% were tested. The FLS/TFA% of 20% was selected for lead slag coarse aggregate concrete because it represents the optimum for the mechanical properties. Mortar specimens of FLS/TFA% equals to 0% and 50% were also investigated for α and β rays. The test specimens for either concrete or mortar were 100 ×100 square plate of 15 mm thickness. VDR2 indicator was used for the completion of the radiation absorption test. The source of α and β rays was SR. 90 and for γ ays, it was Cobalt 60.

3. Results and discussions

3.1. Properties of fresh concrete

Consistency of different mixes was determined using the standard slump test and the results are given in table 5. It is clear that the degree of consistency improves as the FLS/TFA percentages decreases for both types of coarse aggregate due to increasing surface area. It is also clear that the consistency improves with increasing cement content and the rate of improvement depends on the type of the used coarse aggregate.

3.2. Properties of hard concrete

3.2.1. Effect of cement content

The effect of cement content on the compressive strength of the RLS and gravel coarse aggregate concretes at different recycled FLS/TFA percentages are respectively shown in fig. 2 and fig. 3. The two figures clearly demonstrated that the compressive strengths of the two types of concretes are increased with increasing cement content for all percentages of FLS/TFA. The strengths enhancements are more pronounced for lead-slag coarse aggregate concrete as compared with that of gravel coarse aggregate mixes. The tensile strength as a function of cement contents shows also similar trend for both types of lead- slag and gravel coarse aggregate concretes as shown in fig. 4 and 5. The behavior of either the compressive strength or the tensile strength with increasing cement content was expected because as the hydration proceeds, the amount of hydration products increases and their accumulation closes the available pore volumes, which leads to a decrease in the total porosity and finally, increasing the compressive and tensile strengths. Also the strength development depends primarily on the formation of calcium silicate hydrate (CSH) as the main hydration products. Therefore, the formations of CSH phases with high values of cement content will increases and the strength accordingly increases.

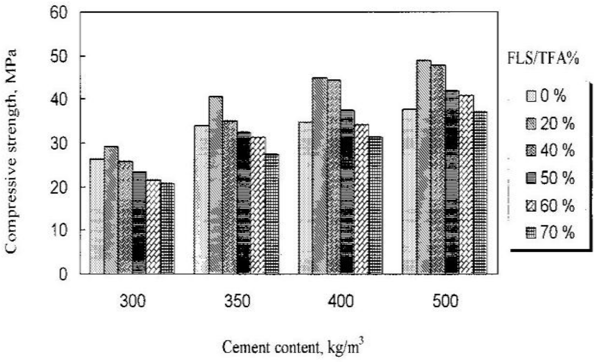

Fig. 2. Effect of cement content on the compressive strength of lead- slag coarse aggregate concrete at different FLS/TFA%.

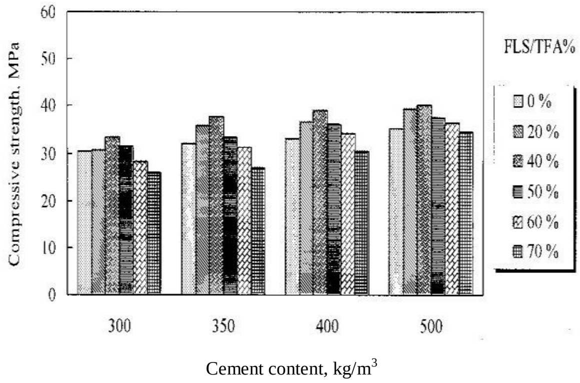

Fig. 3. Effect of cement content on the compressive strength of lead- slag coarse aggregate concrete at different FLS/TFA%.

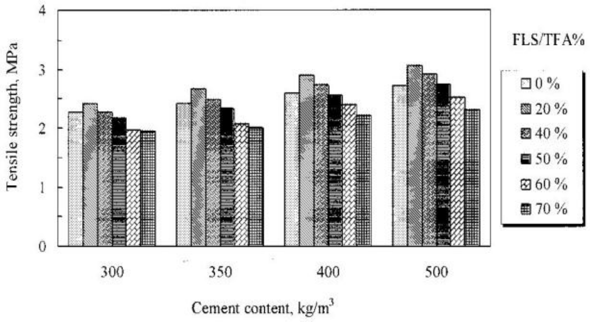

Fig. 4. Tensile strength vs cement content for lead slag coarse aggregate concrete.

3.3. Behavior of concrete at different FLS/TFA%

The effect of FLS/TFA percentages (0, 20, 40, 50, 60 and 70 %) on the compressive strength ratio (σ_c / σ_{co}) of the recycled- lead slag coarse aggregate concrete at cement

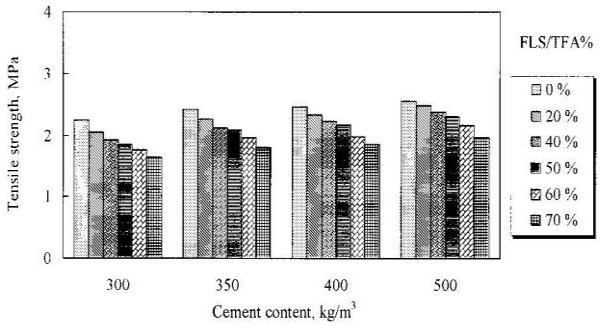

Fig. 5. Tensile strength vs cement content for gravel coarse aggregate concrete.

contents of 300, 350, 400, 500 kg/m^3 is illustrated in fig. 6.

The compressive strength ratio is the ratio between the compressive strength of concretes with partial sand replacement by fine recycled- lead slag (σ_c) to that of 100% sand as fine aggregates (σ_{co}). It is clear from fig. 6 that, with increasing FLS/TFA%, σ_c/ σ_{co} increases up to FLS/TFA% equals to 20%, but beyond this ratio it decreases continuously till it reaches a value less than that of reference specimen (100% sand as fine aggregate). The FLS/TFA% at which the compressive strength becomes lower than that of the reference specimen depends on the cement content. With increasing cement content, a relatively large fraction of sand can be replaced by fine recycled- lead slag with keeping the strength higher than that of the 100 % sand as fine aggregate.

The behavior of the compressive strength for gravel coarse aggregate concrete is represented also in fig. 7. The figure demonstrate similar behavior to that of lead- slag coarse aggregate concrete, i.e. increase in the strength with increasing FLS/TFA% up to certain percentage and after that the behavior is reversed. The FLS/TFA% at which gravel concrete attained its maximum compressive strength is equal to 40%. Figs 6 and 7 also show that the enhancement in the compressive strength ratio is more pronounced with the use of the RLS as coarse aggregate as compared with that gravel concrete. From the chemical composition of the RLS, table 1, it may be concluded that it shows some of hydration reactivity, which

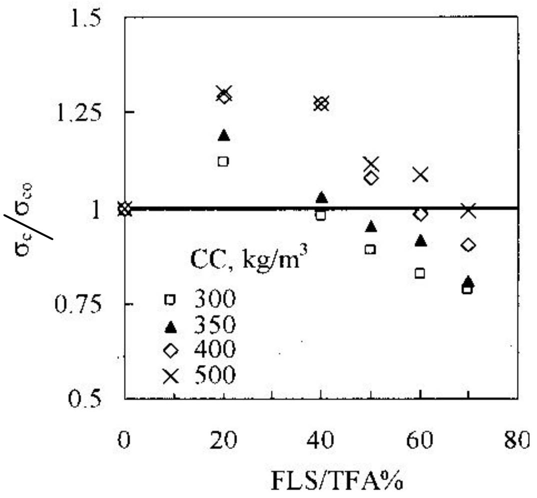

Fig. 6. Compressive strength ratio vs FLS/TFA% for recycled- lead slag coarse aggregate concrete.

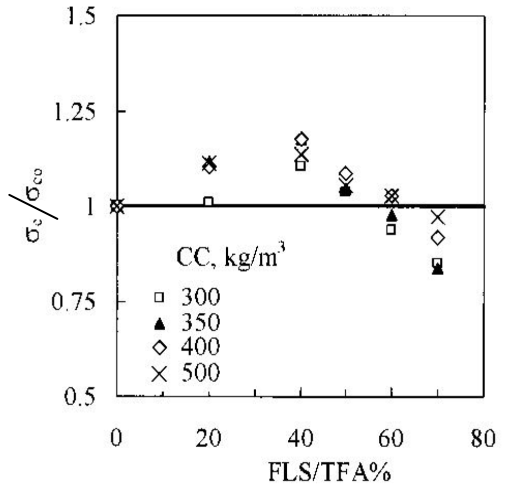

Fig. 7. Compressive strength ratio vs FLS/TFA% for gravel coarse aggregate concrete.

allow it to behave as a pozzolanic when it was mixed with cement. So, using of lead- slag as aggregate enhances a type of aggregate cement paste interface.

However, the using of lead- slag as fine and coarse aggregate exhibits a more hydration reaction than that observed with using the lead- slag as fine aggregate only. Therefore, the mixes fabricated with using recycled- lead slag as coarse aggregate showed the maximum strength at 20% replacement of fine sand by fine recycled- lead slag. While with using gravel as coarse aggregate, it's known that gravel as quartzite compositional materials has an inert behavior towards the reaction with cementatious materials, so it needs more percents of recycled fine lead- slag aggregate to overcome the loss of pozzolanisity due to gravel inert behavior in such mixes. So, 40% FLS/TFA% may be suitable for attaining the optimum strength in this case. With further increase in the replacement of sand by fine recycled- lead slag, it was found that some decreases in the strength are recorded. This may be due to the fact that by increasing the fine lead- slag aggregate without the equivalent required amount of cement to achieve pozzolanic hydration, an adverse effect on the bond in the matrix is occurred.

The effect of FLS/TFA% on the tensile strength ratio of both RLS coarse aggregate and gravel coarse aggregate concretes is shown in fig. 8 and fig. 9 respectively. The tensile strength of the RLS coarse aggregate concrete shows nearly similar trend as that of the compressive strength of the corresponding concrete. On the other hand, gravel coarse aggregate concrete showed a continuously gradual decrease in the tensile strength with increasing FLS/TFA%, which differs from that of the compressive strength of the same concrete. This is because the tensile strength is mainly dependent on the bond strength between the cement paste and aggregate, which is affected by the surface texture of the used coarse aggregate.

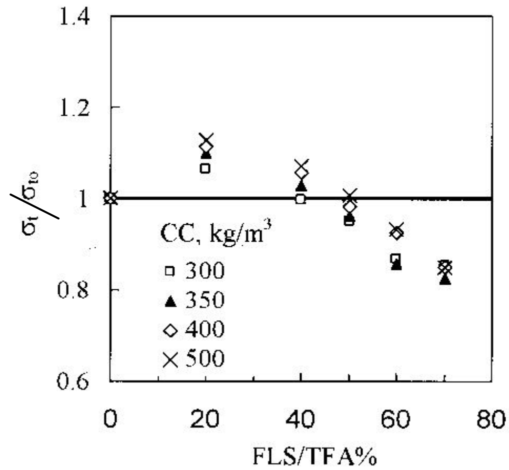

Fig. 8. Tensile strength ratio vs FLS/TFA% for lead- slag coarse aggregate concrete.

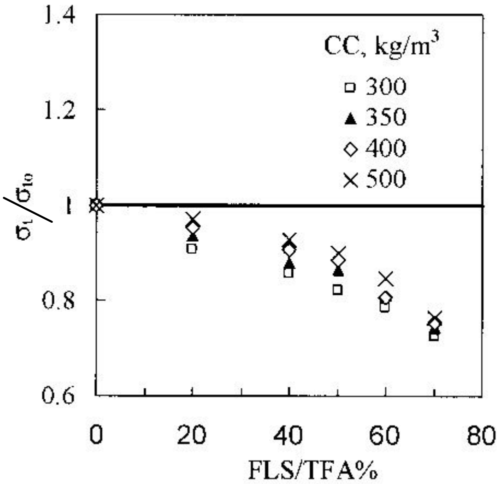

Fig. 9. Tensile strength ratio vs FLS/TFA% for gravel coarse aggregate concrete.

3.4. Comparison between RLS and gravel concretes

Fig. 10 shows a comparison between the compressive strength of the RLS coarse aggregate and gravel coarse aggregate concretes at cement contents of 300 kg/m^3, fig. 10-a, 350 kg/m^3, fig. 10-b, 400 kg/m^3, fig. 10-c, and 500 kg/m^3, fig. 10-d. The figures show that at all FLS/TFA% and cement content of 300 kg/m^3, gravel coarse aggregate concrete recorded higher strength values compared to those of recycled- lead slag coarse aggregate. With increasing cement content, the trend is gradually reversed. At cement content of 350 kg/m^3, the recycled- lead slag coarse aggregate concrete recorded higher strength values at low percentages of FLS/TFA. At higher cement contents (400 and 500 kg/m^3), RLS coarse aggregate concrete showed higher compressive strengths at all FLS/TFA% compared to those of gravel coarse aggregate concrete. This is may be attributed to the fact that at the high cement content, the properties of aggregate plays the main role in controlling the strength of concrete (gravel aggregate showed higher crushing strength compared to recycled- lead slag aggregate). At higher cement contents, the interface strength is a vital factor in controlling the concrete strength.

4. Properties of mortar

The effect of FLS/TFA% on the compressive strength of mortar specimens measured at 7 and 28 days is shown in fig. 11. The figure shows that the compressive strength of mortar at both 7 and 28 days increases with increasing FLS/TFA% up to 50% and beyond that it decreases to lower values but still higher than that of the control specimens (100% fine sand). The figure also demonstrated an increase in the compressive strength with increasing the test age. The compressive strength after 28 days is about 1.5 of that after 7 days for all FLS/TFA%. The effect of sand replacement by lead- slag on the wear resistance of mortar is measured by the ratio of the abraded weight to the original weight of the test specimen (abrasion coefficient, AC%).

The relation between AC % and FLS/TFA% is shown in fig. 12. It is clear that the AC% increases with increasing the ratio of replacement of sand by fine recycled- lead slag, which means lower resistance to abrasion. This of course is expected due the lower Loss Angles value for the RLS. The data presented in fig. 12 fit the following linear relation between the abrasion coefficient and FLS/TFA%:

$$AC\,\% = 0.0875\ (\text{FLS/TFA\%}) + c$$

Where c is constant depend on the abrasion resistance of the control specimen of 100% sand as fine aggregate. In the present work C is equal to 7.

5. Radiation absorption

The results of radiation absorption for mortar and for the both types of coarse lead slag concrete at 20% FLS/TFA percent and that for gravel concrete having 100 % sand as fine aggregate at cement content equals 400 kg/m^3 are given in table 6. It is clear that there is no large difference in radiation absorption capacity of α and β rays between gravel and lead slag coarse aggregate concrete, where gravel concrete absorbed 86% and lead slag concrete absorbed 88%. In the case of mortar some enhancement in the absorption capacity of both α and β rays is observed with replacing sand by 50% FLS compared to mortar specimen of 100% sand as fine aggregate, 88% absorption capacity is recorded for lead slag mortar compared to 82% for sand mortar. The situation is so much difference in the case of γ rays. In this case lead slag coarse aggregate concrete with FLS/TFA equal to 20% recorded absorption

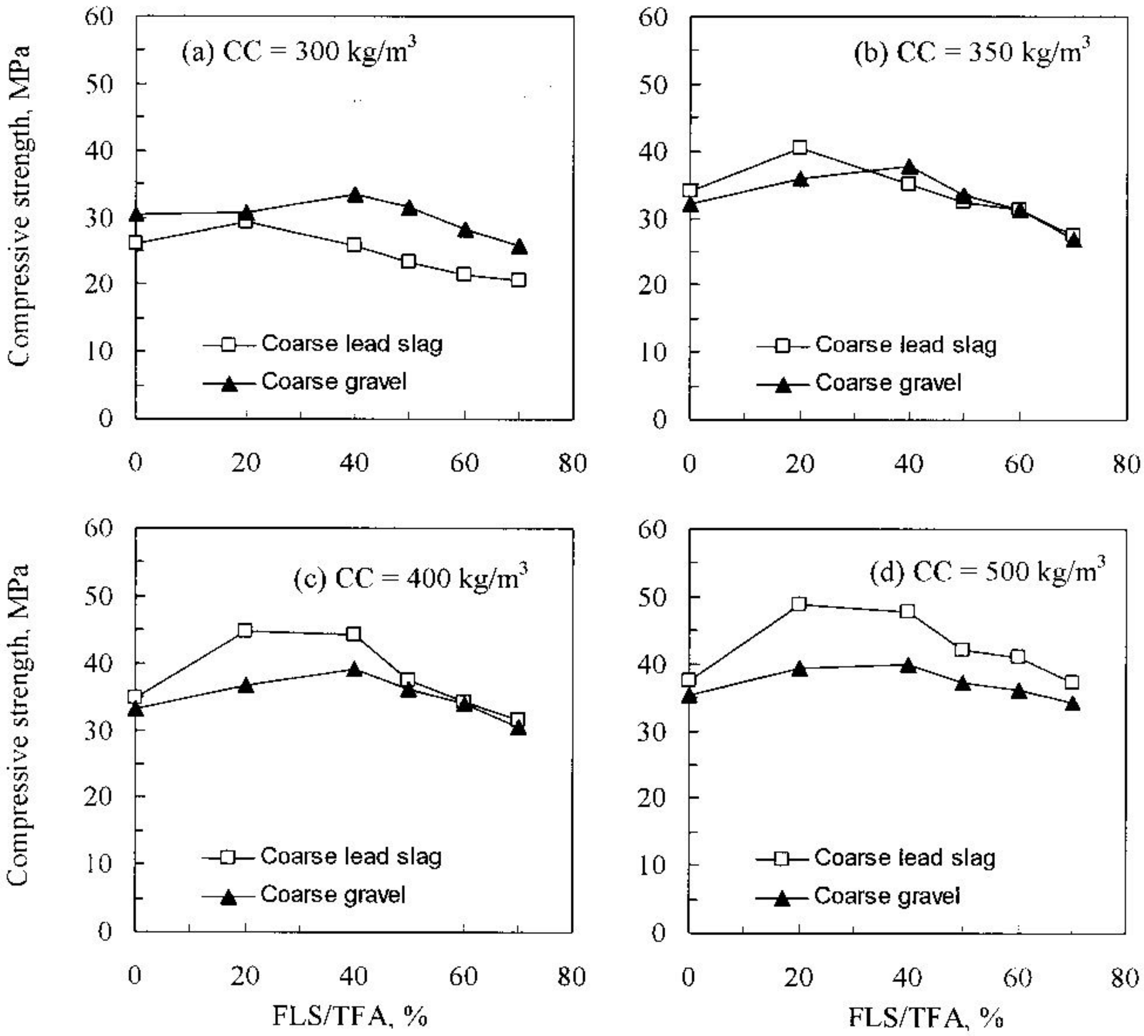

Fig. 10 Comparison between concretes made with either lead- slag or gravel as coarse aggregate at different cement contents and FLS/TFA%.

Table 5
Slump values for gravel and lead- slag coarse aggregate concretes (mm)

Mix type		Gravel concrete				Lead-slag concrete			
FLS/TFA %	W/C	Cement content, kg/m³				Cement content, kg/m³			
		300	350	400	500	300	350	400	500
0		35	45	50	70	30	35	45	65
20		35	45	50	70	30	35	45	65
40	0.5	35	40	50	70	30	35	40	65
50		30	40	45	65	25	30	40	50
60		25	35	45	60	20	30	35	50
70		25	35	35	55	20	30	30	50

Table 6
Radiation absorption test results for concrete and mortar

Mix type	Type of ray	Emission Intensity	Distance (mm)	Used source	Transmitted intensity
Gravel Concrete	α,β□	128, μGy/hrs	30	Sr.90	18, μGy/hrs
	γ	10,μ.curie	20	Co.60	9, m.curie
Lead-slag concrete	α,β□	128, μGy/hrs	30	Sr.90	15 μGy/hrs
	γ	10, μ.curie	20	Co.60	1, μcurie
Mortar FLS/TFA =0%	α,β□	128, μGy/hrs	30	Sr.90	23 μGy/hrs
Mortar FLS/TFA=50%	α,β□	128, μGy/hrs	30	Sr.90	15, μGy/hrs

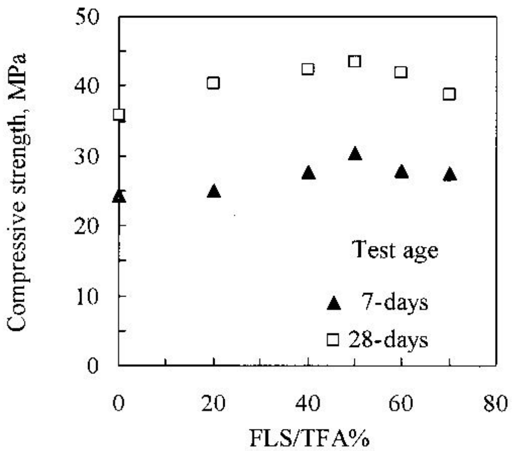

Fig. 11. Effect of FLS/TFA% on the compressive strength of mortar at ages of 7 and 28 days.

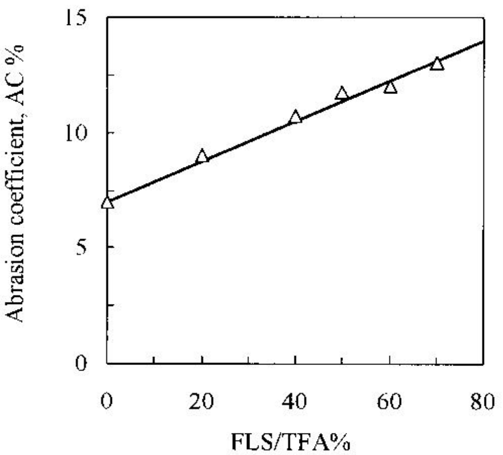

Fig. 12. Effect of FLS/TFA% on the abrasion coefficient of mortar at 7 days.

capacity of about 90% compared to 10% absorption capacity for gravel coarse aggregate concrete with 100% sand as fine aggregate.

6. Conclusions

The results of the present investigation on the use of recycled- lead slag as coarse and fine aggregate in concrete manufacture support the following conclusions:

The use of recycled- lead slag as coarse aggregate and partially replacing the fine sand by fine recycled- lead slag enhanced both the compressive and tensile strength of concrete up to 20% replacement and after that the strength decreased.

The use of gravel as coarse aggregate and partially replacing the fine sand by fine recycled- lead slag enhanced the compressive strength of concrete up to 40% replacement and after that the strength decreased, while the tensile strength almostly decreased all over the range of replacement.

Higher percentages of sand replacement by fine recycled- lead slag can be used without decelerating the strength of concrete below that of 100% fine sand specimens by using relatively higher cement content.

For poor mixes in cement content, gravel concrete recorded higher strength, while coarse recycled- lead slag concrete recorded the highest strength for the rich mixes.

Within the studied range, all percentages of sand replacement by fine recycled lead of mortar showed higher compressive strengths at 7 and 28 days compared to that of 100% fine sand specimen. The optimum percentage of replacement was 50%.

The abrasion resistance of mortar decreased with increasing the percentage value of sand replacement by fine recycled- lead slag.

Lead- slag concrete showed better capacity for radiation absorption when compared with that of ordinary concrete especially for γ rays.

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