Journal of Kerbala University , Vol. 14 No.2 Scientific . 2016

Thermal properties of cement mortar containing waste aluminium fine aggregate

الخواص الحرارية للمونة الاسمنتية الحاوية على مخلفات الالمنيوم كركام ناعم

Dr. Tumadhir M. Borhan[1]   Dr. Hussein Janna[2]
[1)] Roads & Transportation Engineering Department, University of Al-Qadisiyah, Iraq,
E-mail: tumadhir.borhan@qu.edu.iq
[2)] Civil Engineering Department, University of Al-Qadisiyah, Iraq
E-mail: hussein.janna@qu.edu.iq

Abstract

In this research, a study was conducted on the possibility of using aluminum filling (a waste from the manufacture of some building components) as a partial replacement of the natural sand in cement mortar. Different percentages of aluminum filling were used in the production of lightweight mortar. The replacements were (0, 20, 40 and 60%) by volume of the sand. The compressive strength under two different conditions was measured. The results showed that the use of this type of aggregate reduces the compressive strength of cement mortar cubes, tested at ambient temperature, compared to the reference mix which has natural sand. The results also revealed that replacing the sand with 40 and 60% aluminum filling decrease the rate of reduction in compressive strength when the samples tested immediately after heated at 55C^o in an oven. The thermal conductivity test results were positive, where there was a decrease in thermal conductivity with increasing the aluminum waste content.

Keywords: Aluminum filling, cement mortar, compressive strength, thermal conductivity, solid waste management.

الخلاصة

في هذا البحث اجريت دراسة لمعرفة امكانية استخدام برادة الالمنيوم (كاحد الوسائل للحفاظ على البيئة والتخلص من المخلفات الصلبة والناتجة من تصنيع بعض مواد البناء) كركام ناعم للمونة الاسمنتية. تم استخدام برادة الالمنيوم كرمل بنسب استبدال مختلفة لانتاج مونة خفيفة الوزن، وكانت نسب الاستبدال (0، 20، 40، 60)% من حجم الرمل. تم فحص مقاومة الانضغاط للعينات بطريقتين مختلفتين للفحص. بينت النتائج ان استخدام هذا النوع من الركام يقلل من مقاومة الانضغاط المفحوصة في درجة حرارة الغرفة مقارنة بالخلطة المرجعية الحاوية على رمل طبيعي. كما بينت النتائج بان معدل النقصان في مقاومة الانضغاط قد انخفض عند فحص النماذج مباشرة بعد تسخينها في الفرن بدرجة حرارة ٥٥ درجة مئوية. ان فحص معامل التوصيل الحراري كان ايجابيا حيث انخفضت قيمته باستخدام برادة الالمنيوم.

1 Introduction

Industrial solid wastes are a concern to many countries around the world and therefore accumulation of theses wastes represent a significant problem to the environment. In addition to that, the wastes resulting from the damaged or consumed materials such as plastics, broken glasses, iron, aluminum and wood filings, are causing an environmental issue leading to health problem. Moreover the wastes resulting from of municipal solid waste incinerators (MSWI) at wastes treatment plants in many countries of the world results in large amounts of solid waste (called slag waste burning) represent an environmental problem which must be disposed of [1-3]. This requires the development of practical solutions to get rid or eliminate such waste through recycling and re-use it again or by taking advantage of these materials as a partial substitute for some of the construction materials (cement, sand, gravel) used in the production of asphalt or concrete mixes.

The climate in Iraq is suffering from warm atmosphere in summer and cold in winter. The thermal insulation is one of the major engineering problems that need further research in the field of housing and construction. Thus, there is an urgent need to create alternative structural materials with good thermal insulation at the lowest possible cost with acceptable mechanical properties of these materials.

The production of insulating non-structural concrete can be achieved by several methods.One of them is by using lightweight aggregate.This aggregate can be either natural aggregate or industrial aggregate.Recently,lightweight aggregate from waste materials can also be produced[4-6]

The gas formation agent commonly used in manufacturing autoclaved cellular concretes is made of aluminum powder provided mainly from abroad. This increases the cost of producing such concrete type. In order to reduce the cost of this type of concrete, attempts should be made to use recycled aluminum instead. Limited researchers have previously studied the use of aluminum waste in the concrete industry. However, these studies concentrated only to produce a fine powder from this waste as an alternative to aluminum powder used in cellular concrete (autoclaved) industry [7] or using this powder to produce lightweight clay aggregate [8]. Fine powder needs extra cost for grinding.

A step to preserve the natural sources of the construction materials and decreases the cost of producing lightweight concrete by finding alternative materials, this research aims to study the possibility of using waste aluminum (filing) by-product of the doors and windows fabrication as a partial replacement of fine aggregates in cement mortar. The use of recycling materials also helps to prevent the environment from the damage by getting rid of these waste materials. The effect of different aluminum content on the mechanical and thermal properties of cement mortar was investigated.

2Experimental work

This section presented the properties of the materials used in this study with a brief description of the laboratory tests conducted in this research. All tests were implemented in the laboratory of the construction materials at the College of Engineering / University of Al-Qadisiyah.

2.1 Materials used

2.1.1 Cement

ASTM C150-07 [9] Ordinary Portland cement (Type I) manufactured at Al-Muthana cement factory and confirming the Iraqi standard IQS (5-1984) [10] was used in this study. Table 1 describes the chemical and physical properties of this cement.

2.1.2 Fine aggregate

Natural sand from the quarries of AN-Najaf province was used after washing and screening by the standard sieves. The sand confirms the Iraqi standard IQS (45-1984) [11] for fine aggregate. Table 2 shows the physical and chemical properties of the sand used. The table also shows the conformity to the specification in the grading zone (1).

2.1.3 Aluminum filling

Aluminum filing (by product from manufacturing aluminum doors and windows) was used to substitute the natural sand in cement mortar. The substitution ratios were (0, 20, and 40.60%) by volume of sand. It was screened on the sieve number (4.75) to be close to the sizes of natural aggregates as shown in the Table 3.

2.2 Mixes and mixing procedure

The volumetric mixing ratio (1:3) (cement: sand) was adopted in this study. The water to cement ratio (w / c) of 0.45 was used and kept constant for all mixes. The mortar components were mixed manually on a solid, clean and non-porous surface (flat iron containers). The dry materials (cement, sand and the aluminum filling) were mixed first (Figure 1) then the water was added gradually to the mix till getting a homogeneous color mix. The mortar specimens were cast in the moulds in three layers compacted using steel rod and followed by trawling the surface to level it. The specimens were cured at laboratory temperature while covered by polyethylene sheets for 24 hours from time of adding the water to the mix. The specimens were demolded carefully then placed in water tank for 28 days and tested in saturated dry surface condition.

2.3 Testing

Mortar cubes of (50 * 50 * 50) mm in a total number of (24) were used to conduct compressive strength test according to ASTM C109 [12]. Six cubes for each test were adopted. Three of them were examined in saturated dry surface condition. The other three were placed in an oven with a temperature up to 55°C for a period of three hours (the duration of the peak period in Iraq). The cubes were weighted before the test to determine its density. The splitting tensile strength test was conducted according to ASTM C 496 [13] Cylinders in a total of (15) were cast for this purpose (3 for each mix). The dimensions of these cylinders are (10 cm diameter and 20 cm height). The specimens were cured for 28 days in water tank then tested in saturated dry surface condition. The thermal conductivity coefficient was tested using the steady-state guarded hot plate method (ASTM C 177) [14] (Figure 2). Ten discs, measured 100 mm in its diameter and the height was 50 mm, were used for this purpose, two for each mix. The thermal conductivity (*k*) was calculated using the following equation:

$$k = \frac{Q.L}{A.\Delta T}$$

Where:

Q: The amount of heat conducted through the samples = the current (I) multiply by the voltage (V) passing through the heater from the power supply equipment.
L: specimen thickness
A: cross-section area
ΔT: difference in temperature on both sides of the sample

3 Results and discussion

3.1 Fresh density

The density of the specimens was decreased with increasing aluminum filling content. The reduction was up to 5.9% as shown in Figure 3.

The soft grains of aluminum filling have the ability to react chemically with $Ca(OH)_2$ resulted from the hydration of the silicates. Such reaction leads to the forming of hydrogen bubbles throughout the mixture [7].

$$2Al + 3Ca(OH)_2 \rightarrow 3(CaO).Al_2O_3 + 3H_2$$

The Specimens swelling were observed after short period of mixing and casting which indicates that this interaction occurs and the gas was liberated (Figure 4).

3.2 Compressive strength test results

Figure 5 shows the effect of aluminum filling content on the compressive strength of cement mortar. It can be seen that the compressive strength of the specimens tested at normal temperature decreased by 42-85% when the filling content increases compared to the reference mix. This is attributed to the fact the strength of the waste materials is less than that of the natural aggregate as well as the gas formation explained in section 3.1. The increase in aluminum filling content leads to increase the amount of voids in mortar structure and thus, decrease the compressive strength.

Heated the specimens in the oven for three hours at 55C^{o} decreases the compressive strength for all mixes (Figure 6). However, replace the sand with 40 and 60% aluminum filling decrease the rate of reduction in compressive strength by 12% and 23.8% respectively. The reason for this results maybe due to effect of heat for accelerating the hydration of cement compounds and reduces the voids in the specimens, which leads to increase the strength accordingly.

The splitting tensile strength results have the same trend of that in compressive strength (Figure 7). The splitting tensile strength of the specimens with 20, 40,and 60% replacement decreases by 83.7, 86.7 and 90.3% respectively.

3.3 Thermal conductivity

Figure 8 shows that increasing the aluminum content have a positive effect in reducing the amount of transmitted heat through the thickness of the specimens. Increasing the aluminum content leads to increase the formation of the voids due to gas liberation, as previously mentioned, which in turn reduces the coefficient of thermal conductivity of the mortar. Thus, this type of mortar or concrete has better insulation capability compared to normal mortar or concrete.

4 Conclusion

From the results presented in previous section, it can be concluded that it is possible to use aluminum filing in the production of lightweight and heat-insulating concrete unites. The experimental work results lead to the following conclusions:

1- The use of aluminum filling as a partial replacement of fine aggregate reduces the density of cement mortar.
2- For the heated specimens, the reduction in compressive strength is less than that at ambient temperature.
3- Using aluminum filling in cement mortar reduces its splitting tensile strength.
4- The use of aluminum filling has a positive effect on thermal insulation with less thermal conductivity coefficient value obtained when increase the filing content in the mixture.

5 References

1. Eldin, N.N. and Senouci, A.B., *Rubber-tire particles as concrete aggregate.* Journal of materials in civil engineering, 1993. **5**(4): p. 478-496.
2. Shi, C., Wu, Y., Riefler, C. and Wang, H., *Characteristics and pozzolanic reactivity of glass powders.* Cement and Concrete Research, 2005. **35**(5): p. 987-993.
3. Borhan, T.M., *Properties of glass concrete reinforced with short basalt fibre.* Materials & Design, 2012. **42**: p. 265-271.
4. Borhan, T.M., *Effect of using recycled lightweight aggregate on the properties of concrete.* Journal of Babylon university, 2015. **23**(2): p. 453-464.
5. Kou, S., Lee, G., Poon, C. and Lai, W., *Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes.* Waste Management, 2009. **29**(2): p. 621-628.
6. Siddique, R., Khatib, J. and Kaur, I., *Use of recycled plastic in concrete: a review.* Waste management, 2008. **28**(10): p. 1835-1852.
7. Araújo, E.G.d. and Tenório, J.A.S. *Cellular concrete with addition of aluminum recycled foil powders*. in *Materials science forum*. 2005. Trans Tech Publ.
8. Bajare, D., Korjakins, A., Kazjonovs, J. and Rozenstrauha, I., *Pore structure of lightweight clay aggregate incorporate with non-metallic products coming from aluminium scrap recycling industry.* Journal of the European Ceramic Society, 2012. **32**(1): p. 141-148.
9. ASTM C150-07. 2007,"*Standard specification for portland cement", Book of standards* vol. 04.01, 8pp**.**
10. Iraqi Specification, No.5. *(1984), Portland cement*
11. Iraqi Specification, No.45. *(1984), Aggregate from natural sources for concrete and construction.*
12. ASTM C109, 2012 *"Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)".*
13. ASTM C 496/C496M-04, (2005), *"Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens",* Annual Book of ASTM Standards, Vol.01.01, PA.
14. ASTM C177-04, 2004. *Standard test method for steady state heat flux measurements and thermal transmission properties by means of the Guarded-Hot-Plate apparatus*. 2004. American Society for Testing and Materials Philadelphia, PA.

Table 1 Chemical composition and physical properties of Ordinary Portland Cement

Oxide composition	Oxide content %	Physical properties	
CaO	60.2	Fineness (Blaine) cm^2/gm	290
SiO_2	19.54	Initial setting time (Vicat) (min)	95
Al_2O_3	10.42	Final setting time (Vicat) (Hrs:min)	3:35
Fe_2O_3	4.36	Soundness (Autoclave method) %	0.1
MgO	2.03	Compressive strength (MPa)	
SO_3	1.53	3 days	16.53
Free CaO	1.04	7 days	24.74
L.O.I	0.96	Major components of cement	
I.R	0.95	C_3S	41.24
L.S.F	0.79	C_2S	25.01
		C_3A	11.63
		C_4AF	13.26

Table 2 Grading and physical properties of fine aggregates

Sieve opining size (mm)	Percentage passing %	Limits of IQS (45-1984) zone(1)
10	100	100
4.75	99	90 - 100
2.36	85.6	60 - 95
1.18	40.1	30 - 70
0.60	17	15 - 34
0.30	5	5 - 20
0.15	0.3	0 – 10
Properties		value
SO_3 %	0.05	≤ 0.5
Material finer than (75µ) %	4	≤ 5

Table 3 Grading of Aluminum filling

Sieve opining size (mm)	Percentage passing %	Limits of IQS (5-1984) zone(1)
10	100	100
4.75	100	90 - 100
2.36	92.6	60 - 95
1.18	53.5	30 - 70
0.60	29.5	15 - 34
0.30	7.5	5 - 20
0.15	1.7	0 – 10

Figure 1 Dry materials

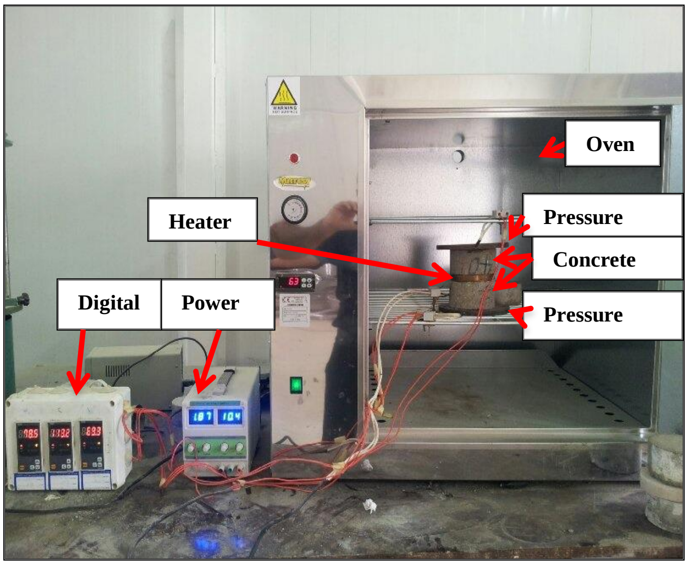

Figure 2 Thermal conductivity test

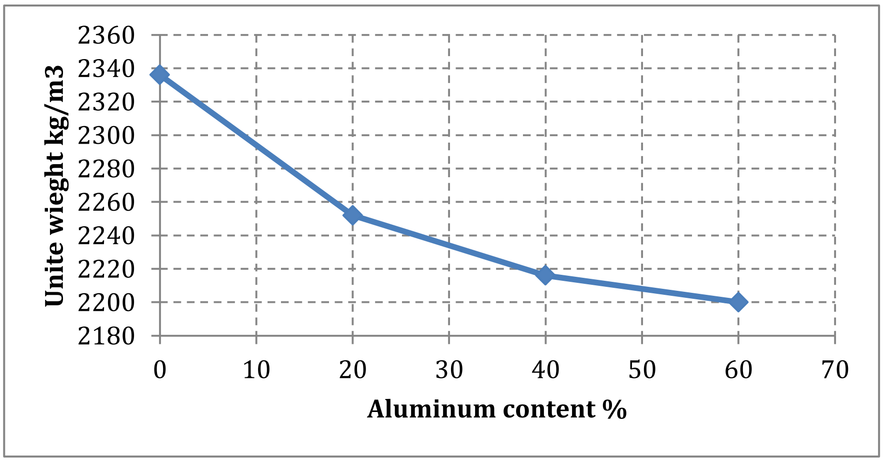

Figure 3 Effect of Aluminum filling content on fresh density of cement mortar

Figure 4 Swelling of specimens after short period of mixing and casting

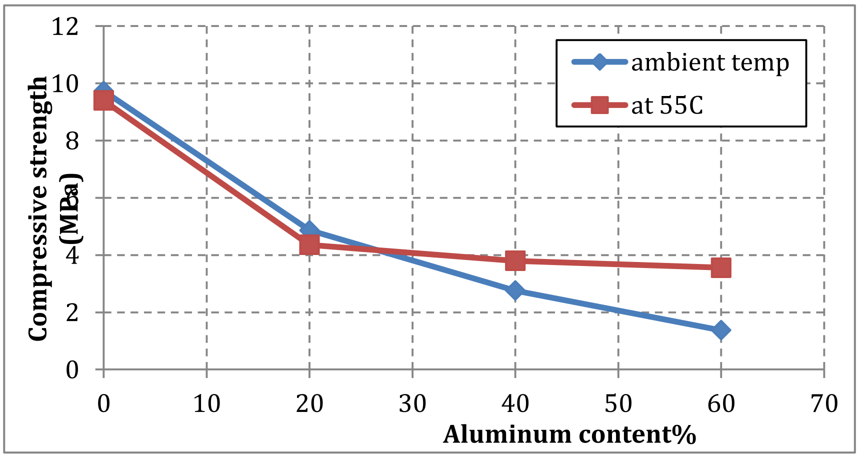

Figure 5 Aluminum filling content versus compressive strength of cement mortar

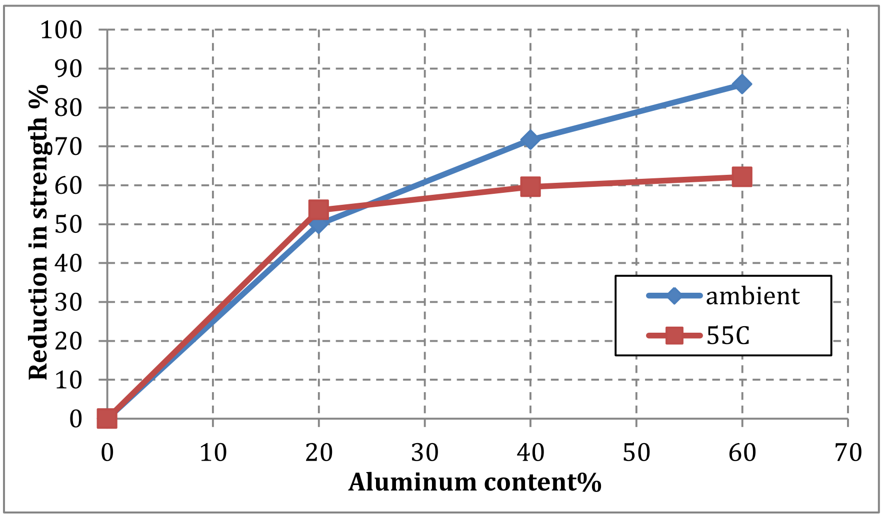

Figure 6 Aluminum filling content versus reduction in compressive strength

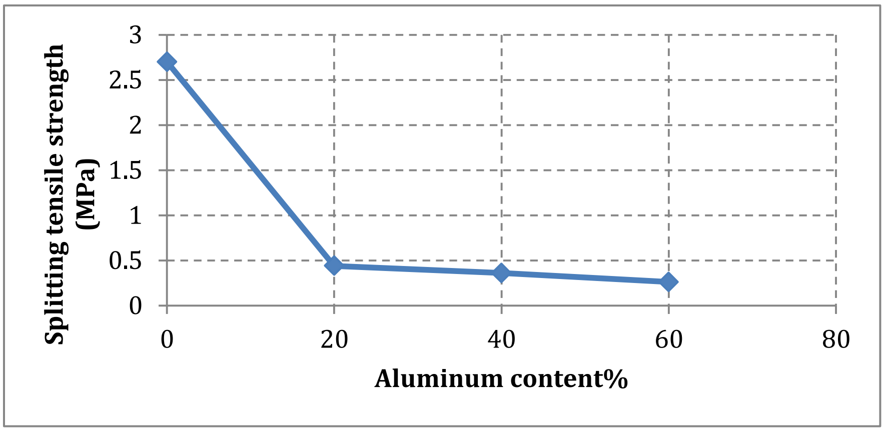

Figure 7 Aluminum filling content versus splitting tensile strength of cement mortar

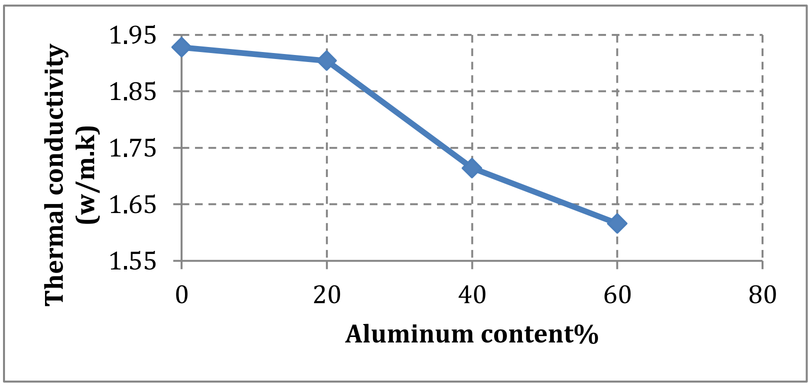

Figure 8 Aluminum filling content versus coefficient of thermal conductivity