Recycling of Aluminum Byproduct Waste in Concrete Production

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ABSTRACT

This experimental investigation was performed to evaluate the viability of using aluminum byproduct (waste) in the production of low strength concrete. Aluminum byproduct (ALBP) is obtained from the use of aluminum alloys in construction industry. It typically comes in the form of thin, flexible and small strips that can be used in concrete production. The effects of incorporation of ALBP on the properties of fresh and hardened concrete were experimentally investigated. The study evaluated the density, swelling, compressive and flexural strengths and workability properties of concrete mixtures to which aluminum byproduct was added in different proportions (0%, 5%, 10%, 15%, 20% and 25%) by weight of cement. Compression and flexural strength tests were carried out to evaluate the strength properties of hardened concrete. Workability and swelling of fresh concrete were also monitored and recorded. The test results indicate that ALBP reacts with cement hydration products, causing considerable decreases in workability, compressive strength, flexural strength and density of plain concrete with the addition of ALBP. The reduction in density of concrete due to hydrogen gas released from the reaction of aluminum with alkaline cement paste solution can be positively viewed to produce lighter concrete. The results also indicate that the strength of concrete with ALBP can still be considered sufficient for some applications. Overall, the results of this study demonstrate the viability of using ALBP in the production of low-strength and lighter concrete and can help toward a more sustainable construction.

KEYWORDS: Recycling, Aluminum byproduct (waste) (ALBP), Concrete production.

INTRODUCTION

Aluminum alloys are widely used in engineering structures, where light weight or corrosion resistance is required. The use of aluminum alloys in engineering applications, primarily in residential building components, such as: facades, sidings, windows, doors and guard rails, results in a tangible waste that poses an environmental problem and thus needs management and recycling. According to the Aluminum Association, more than 2 billion pounds of construction materials were shipped in North America in 2009 for construction. About 85% of aluminum is used for wrought products, such as: rolled plates, foils and extrusions, in which Al is the predominant metal. More than 3.4 million tons of aluminum went into the U.S. solid waste stream in 2009 as per the Environmental Protection Agency.

The aluminum byproduct waste (ALBP) typically comes in the form of small size, thin and flexible particles as can be seen in Fig. 1. The intent of this study is to evaluate the potential use of this waste in concrete applications.

An important aspect with this regard is the reaction of aluminum metal with cement paste solution. Under

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normal circumstances, aluminum does not react with water, as an impermeable protective layer of aluminum oxide (alumina) forms on the surface of aluminum particles, preventing water from coming into direct contact with the aluminum metal. However, in a cement-based solution, which is highly alkaline, the reaction of aluminum proceeds to form aluminum hydroxide and hydrogen gas. Aluminum hydroxide goes into the solution in the presence of reaction promoters, such as: alkalis, calcium oxide and hydroxyl ions.

Figure (1): Aluminum byproduct (ALBP)

A number of reaction promoting approaches have been investigated for the aluminum-water reaction in the literature (U.S. Dept. of Energy, 2008). These include the addition of hydroxide promoters such as NaOH (Belitskus, 1970; Stockburger et al., 1992), oxide promoters such as Al_2O_3 (US Patent 6,582,676, 2003) and salt promoters such as NaCl and KCl (International Patent Application PCT/CA2006/ 001300, 2007). An international patent application has also indicated that oxide and salt additions may be combined to promote the reaction of aluminum with water at 20^oC (International Patent Application PCT/US2006/00180, 2006). The preferred oxide is calcium oxide and the preferred salt is sodium chloride. These additions act to disrupt the aluminum oxide layer on the aluminum metal. So, the key to inducing and maintaining the reaction of aluminum with water at room temperature is the continual removal and/or disruption of the hydrated alumina layer. These promoters typically exist in cement paste solution, encouraging and increasing the reactivity of aluminum in concrete.

On the other hand, aluminum is oxidized by water to produce hydrogen and heat. This conversion is of interest for the production of hydrogen through reactions between aluminum-based metals and water (U.S. Dept. of Energy, 2008; U.S. Patent Application 20060034756, 2006). All of the aluminum-based approaches propose methods to circumvent the protective layer of aluminum oxide, thus allowing the reaction with water to proceed. The hydrogen produced *via* such aluminum-water reaction might be employed to power fuel cell devices for portable applications, such as emergency generators and laptop computers. Similarly, the generation of hydrogen gas can be employed to reduce the density of concrete if this reaction is controlled in concrete mixtures. The release of hydrogen produces bubbles that can be used to create voids, thus reducing the density of concrete.

With the increasing awareness about the environment, limitations on landfill space and rapid increase in disposal cost, the usage or recycling of waste materials and byproducts has become of increasing interest worldwide. According to the concept of industrial ecology, the detrimental effects of industries on the environment can be considerably reduced if a byproduct of one industry can be used as a raw material for other industries (Meyer, 2009; Matsunaga et al., 2009). The major byproducts of metal industries that include heavy weight raw materials are: steel, like steel shots such as cast iron and steel, copper, brass, aluminum and bronze.

The use of industrial byproducts in concrete is considered as a sustainable construction development, since it helps optimize cement, concrete and other construction materials with satisfactory performance, in terms of both safety and serviceability. This can be achieved at lower direct cost (the cost of manufacturing cement and concrete) and indirect cost (the cost of landfills, energy and cleaning possible pollution from the environment).

Examples of industrial wastes and byproducts used as replacements or supplements for Portland cement or aggregates in making cement-based materials include fly ash (Ahmaruzzaman, 2010), coal ash (Naik et al., 2003; Marroccoli et al., 2010), silica fume (ACI, 2006; ASTM), recycled concrete (Limbachiya et al., 2000), waste/recycled plastics (Siddique et al., 2008), scrap tires (Khaloo et al., 2008), waste glass (Bashar and Ghassan, 2008; Pezzi et al., 2006), rice husk ash, municipal solid waste ash, wood ash, volcanic ash, cement kiln dust, foundry sand (Tonnayopas et al., 2008; Siddique et al., 2011; Kaur et al., 2012; Gurpeet Singh and Siddique, 2012; Al-Zubaidi et al., 2013) and brass (Al-Zubaidi et al., 2013). Many studies have been carried out to investigate the possibility of utilizing large volumes of waste materials and byproducts in civil engineering construction, including retaining structures, road reconstruction, landfill liners, asphalt concrete, concrete barriers and pavement bases (Siddique, 2008; Goodhue et al., 2001; Javed and Lovell, 1995; Kleven et al., 2000; Yüksel and Bilir, 2007).

This research evaluates the behavior of fresh and hardened concrete made by adding industrial byproduct waste (ALBP) in different proportions. ALBP was chosen for three main reasons: (1) ALBP interacts with water in alkaline solution and produces gas, reducing the density of concrete and thus leading to lighter concrete, (2) ALBP is an available byproduct and cheap industrial waste material and (3) ALBP is a daily industrial waste that represents an environmental issue, requiring management and recycling. These aspects motivated this research to explore the suitability of such byproduct for concrete applications, especially for low-strength concrete.

Control mixes without ALBP and concrete with different percentages of ALBP ranging from 5% to 25% by weight of cement were tested in this study. Workability and swelling of fresh concrete, as well as compressive and flexural strengths of the hardened concrete were evaluated. Also, the density of both fresh and hardened concrete was evaluated. The results were used to evaluate the viability of using ALBP in concrete applications, particularly in the production of light and low-strength concrete.

Experimental Program

The effect of adding ALBP to concrete in different proportions by cement weight on the properties of fresh and hardened concrete was investigated. Concrete properties, such as: density, swelling, workability and compressive and flexural strength evolution, were evaluated.

Materials Used

The control mixture (without ALBP) and five concrete mixtures with ALBP, making a total of 6 main mixtures were designed and tested in this study. Table 1 presents the concrete mixture proportions for the main six mixtures. A concrete compressive strength in the range of 20-25 MPa was targeted in this study, which can be achieved with local materials at a w/c ratio of around 0.7. Furthermore, the high w/c ratio was considered to compensate for the possible loss in workability due to the addition of ALBP, as the study was targeted to explore potential applications with low concrete compressive strength requirements.

Table 1. Concrete mix proportions with and without aluminum byproduct

Control Mix-0			Mix - 5%	Mix - 10%	Mix - 15%	Mix - 20%	Mix - 25%
Cement	(kg)	320	320	320	320	320	320
Water	(kg)	229	229	229	229	229	229
20 mm CA	(kg)	550	545	540	535	532	527
10 mm CA	(kg)	370	367	364	361	357	354
5 mm FA	(kg)	670	664	659	653	647	642
Dune Sand	(kg)	300	298	295	293	290	288
SP 700 % by Cement Weight		0.6	0.6	0.6	0.6	0.6	0.6
AL BP % by Cement Weight		0	5	10	15	20	25

Cement

Ordinary Portland cement (type I) conforming to ASTM C150/C150M-09 was used. The chemical composition and physical properties of the cement used are presented in Table 2.

Table 2. The chemical analysis and physical properties of the cement used

Oxide composition	**Chemical properties**	
	Percentage by weight	**Limits of specifications ASTM C150/C150M-09**
Silica (SiO_2)	20.5	------
Lime (CaO)	61.3	------
Iron oxide (Fe_2O_3)	3.10	≤ 6.0
Alumina (Al_2O_3)	5.8	≤ 6.0
Magnesium oxide (MgO)	3.65	≤ 6.0
Sulfate (SO_3)	2.32	≤ 3.0
Tricalciumaluminate (C_3A)	7.38	≤ 8.0
Ignition loss	2.75	≤ 3.0
Insoluble residue	0.63	≤ 0.75
Physical properties		
Physical property	**Test result**	**Limits of specifications**
Specific surface area (Blaine), (m^2/kg)	310	≥ 260
Setting time (Vicat) Initial (minutes) Final (minutes)	 105 235	 ≥ 45 ≤ 375
Compressive strength (MPa) Strength at: 3days 7days	19.50 28.70	≥ 7.0 ≥ 12.0

Aggregates

Normal weight natural sand with a maximum particle size of 4.75 mm was used as fine aggregate. Locally available gravel with a maximum size of 20 mm was used as coarse aggregate. Testing of coarse and fine aggregates was carried out according to ASTM C33/C33M-08.The grade size distribution of fine and coarse aggregates as well as the ALBP particles is shown in Figure 2. The physical properties for the sand and the coarse aggregate used in this study are reported in Tables 3 and 4, respectively. The size distribution of the sand and the coarse aggregate conformed to the requirements of ASTM C33/C33M-08.

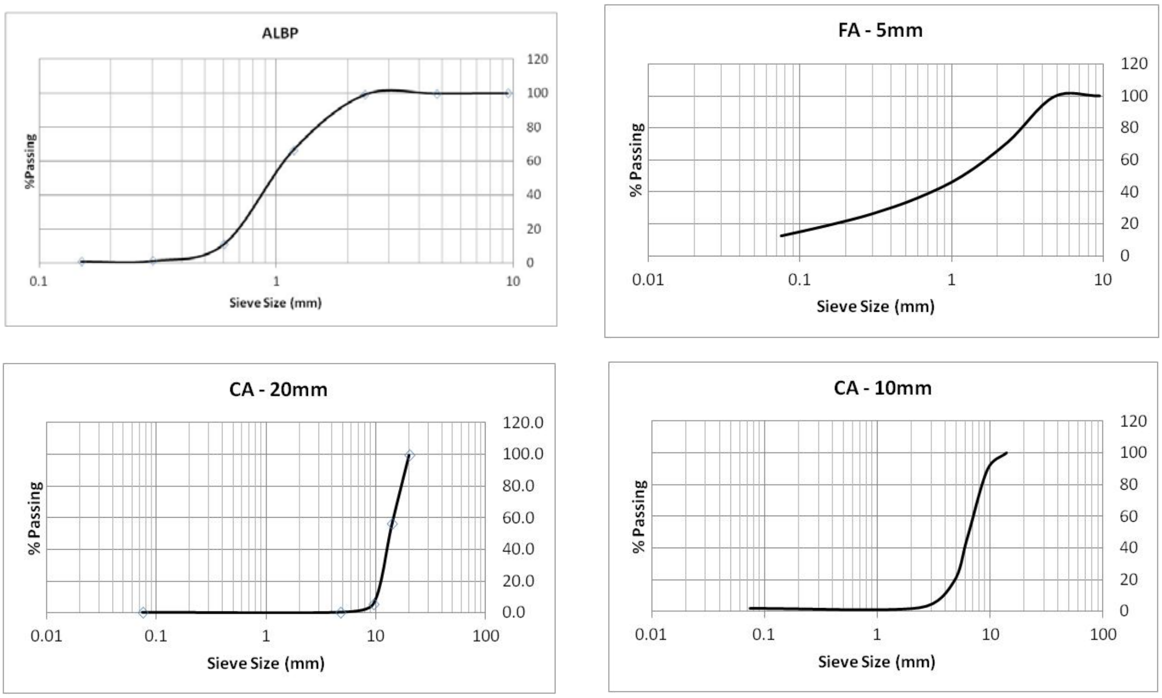

Figure (2): Grading of FA, CA and ALBP

Table 3. Grading and properties of fine aggregate

Sieve size (mm)	**Percentage passing**	**Limits of specifications ASTM C33/C33M-08**
9.5	100	100
4.75	98	95–100
2.36	92	80–100
1.18	84	50–85
0.60	57	25–60
0.30	23	5–30
0.15	3	0–10
Property	**Result**	
Bulk specific gravity	2.6	
Absorption, %	1.4	
Sulfate content as SO_3, %	0.24	

Table 4. Grading and properties of coarse aggregate

Sieve size (mm)	Percentage passing	Limits of specifications ASTM C33/C33M-08
63	100	100
50	100	95–100
25	65	35–70
12.5	25	10–30
4.5	4	0–5
Property	**Result**	
Bulk specific gravity	2.62	
Absorption, %	0.70	
Sulfate content as SO_3,%	0.08	

Aluminum Byproduct (ALBP)

Figure 1 shows a photograph of the ALBP used in this study. It typically comes in the form of thin, flexible and small strips of variable sizes. Size distribution of the ALBP is shown in Figure 2. This aluminum waste is obtained from making and using aluminum alloys for engineering applications, primarily in residential building elements, such as: facades, sidings, windows, doors and guard rails. Aluminum filing waste used is of small size and granulated with a maximum size of around 3 mm as shown in Figure 2. ALBP was added to the concrete at different proportions ranging from 5% to 25% by weight of the cement.

Admixtures

High range water reducing along with set retarding concrete admixture for concrete with the brand name Tuf Flow SP 700 was used in all concrete mixes. SP 700 provides good workability retention in hot climates and is suitable for use with all types of Portland cement and cement replacement materials, such as: PFA, GGBS and Micro-silica. SP 700 comes as a dark brown liquid with a specific gravity of 1.230 at 25°C, pH of 8-10, chloride free, with alkali content; typically less than 56.5g, Na_2O equivalent/ liter of admixture SP 700 complies with ASTM C-494, type D and G and EN 934: 2.

Concrete Mix Proportions

A control mix without aluminum byproduct (Mix-0%) and five concrete mixtures of the same w/c ratio with ALBP (Mix-5% to Mix-25%) were designed and tested in this study. A concrete cylinder compressive strength in the range of 20-25 MPa was targeted in this study, which can be achieved with local materials at a w/c ratio of around 0.7. Furthermore, the high w/c ratio was considered to compensate for the possible loss in workability due to the addition of ALBP, as the study was targeted toward potential applications with low concrete compressive strength requirements. ALBP was added at different proportions ranging from 5% by cement weight (Mix-5%) to 25% by cement weight (Mix-25%). The concrete mix proportions for all mixes are presented in Table 1. All mixes were prepared in the lab using a laboratory mechanical drum mixer.

Casting of Specimens

Sufficient test samples were cast from each concrete mix. The test samples included standard cubes (150 mm x 150 mm x 150 mm) for compressive strength test and density measurement, standard cylinders (150 mm x 300 mm) for unit weight and swelling measurements and standard concrete beams (500 mm×100 mm×100 mm) for flexural strength test. After casting, all test specimens were covered with plastic sheets and stored at room temperature in the casting room. After 24 h, the specimens were removed and put into a water-curing tank until the day of testing. Then, all compressive and flexural strength tests were performed in triplicate at 7 and 28 days.

Measured Concrete Properties

Fresh Concrete Properties

Fresh properties of concrete, such as: slump flow and unit weight, were measured for all concrete mixes as per ASTM C143/C143M-12. After casting the cube and the cylinder specimens, the concrete swell due to the reaction of ALBP with the cement paste and the swelling amount were measured after stabilization was reached.

Hardened Concrete Properties

Six cubes and four concrete beams were prepared from each concrete mix. The test samples were cured in standard conditions and tested at the age of 7 and 28 days. For the compressive strength test, the cube specimens were placed on the bearing surface of a digital compression testing machine. The maximum load was noted and the compressive strength was calculated as per ASTM C39. For the flexural strength test, the standard beams were tested under third point loading configuration according to ASTM C78 using a hydraulic universal testing machine (UTM). Load point and mid-point deflections were recorded.

RESULTS AND DISCUSSION

Workability

Slump is a measure of workability of fresh concrete. The slump results for all concrete mixtures are shown in Fig. 3 and presented in Table 5. Value of slump for the control Mix-0% (without ALBP) mixture was 160 mm, while those of Mix-5% to Mix-25% (with ALBP mixtures) were observed to be 108, 76, 88, 65 and 12mm, respectively .The addition of ALBP reduces the slump flow of the concrete relative to the control as can be seen in Table 5. This may be attributed to two reasons; one is mechanical and the other is chemical, with the latter being more of interest. The aluminum particles with variable sizes consume some of the paste volume for coating and mechanically hinder the flow of concrete. The chemical reason is related to the reaction between the aluminum metal and water in the alkaline medium, forming aluminum hydroxide and releasing hydrogen gas. With the reaction progress, aluminum hydroxide goes into the solution and disrupts the alumina-sulfate balance ratio in the concrete mixes, which in turn disrupts the setting properties and forms compounds (such as hydrogarnet), reducing the slump and potentially leading to flash setting as can be seen at the high dosage of ALBP of 25%. The addition of ALBP in the range between 10% and 20% has similar reductions in slump. Beyond that range, ALBP significantly reduces the slump of concrete and the concrete becomes no longer workable. This suggests that if ALBP at a high dosage is to be used, the composition of cement, specifically sulfate and alumina, should be reconsidered as compared to that of typical Portland cement shown in Table 2.

Table 5. Concrete slump test results

Mixture no.	Slump (mm)	
	Fresh concrete	
	Value (mm)	Percentage decrease
Mix-0	160	0
Mix-1	108	33
Mix-2	76	53
Mix-3	88	45
Mix-4	65	59
Mix-5	12	93

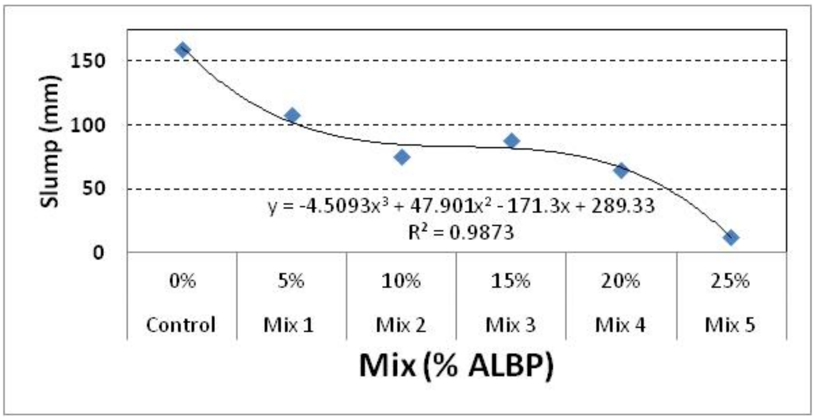

Figure (3): Effect of ALBP% on concrete slump values

Concrete Swelling

Swelling for the six concrete mixtures containing 0%, 5%, 10%, 15%, 20% and 25% ALBP was measured after casting. Swelling test was performed after the concrete cube and cylinder specimen dimensions have stabilized. The increase in the specimen height was measured afterward typically 1 hour after casting. Fig. 4 presents photographs showing the swelling of the concrete samples. The swelling test results are shown in Table 6 and plotted in Fig. 5 for all concrete mixes. It can be seen that the swelling value increases with the increase of ALBP percentage in concrete mixtures. Fig.5 shows that the swelling of concrete due to the addition of ALBP increased linearly with the percentage of ALBP. The maximum swelling value of all mixtures was 33 (1H)(mm) (after 1 hour) for Mix-25%. The swelling of the concrete is attributed to two main mechanisms. The first one is related to the chemical reaction between the aluminum metal and the alkaline solution in the cement paste. The reaction produces aluminum hydroxide which goes into the solution in the highly alkaline medium. Hydrogen gas creates bubbles that try to escape to the surface, thus creating voids and increasing the volume of concrete. Another possible reaction is between alumina and cement hydrates that can form early ettringite which is expansive in nature, thus increasing the volume of concrete similar to the case when expansive cement is used in concrete. The extent of these two possible reactions depends on the amount of ALBP in concrete, thus determining the extent of associated swelling, which is consistent with the results presented in Table 6.

Figure (4): Photograph showing the swelling of concrete samples

Table 6. Swelling test results

Mixture no.	Swelling (1H) (mm)	
	Fresh concrete	
	Value	Percentage increase
Mix-0	0	0
Mix-1	10	10
Mix-2	20	20
Mix-3	27	27
Mix-4	30	30
Mix-5	33	33

Concrete Density

The concrete density values for all mixtures with and without aluminum byproduct for fresh and hardened concretes are shown in Table 7. The density of the control mixture was 2437kg/m^{3}for fresh concrete and 2337 kg/m^{3}for hardened concrete. The concrete density was found to decrease with the addition of ALBP and the maximum reduction was found to be around 17% when ALBP was added at 25 % by cement weight as shown in Table 7. Fig.6 plots the relation between the concrete density and the percentage of ALBP. It was found that the concrete density decreased as the percentage of aluminum byproduct increased, following a power function with a high coefficient of correlation $R^2\approx$ 0.99. The reduction in density of concrete is attributed to the increase of concrete volume (swelling) due to the reaction between the aluminum metal and the alkaline solution in cement paste as previously discussed. The hydrogen gas released and the formation of expansive products from the exothermal reaction between the aluminum and cement hydrates contribute to the increase in volume, thus reducing the density of concrete. It should be noted that not all of the hydrogen gas is entrapped in the mixture and some of the gas leaves and escapes the system at a very early age. If the hydrogen gas is controlled and forced to be entrapped in the concrete mixture, the concrete density will be much lower than that obtained in this study. This will be the topic of a future paper in which the released gas will be controlled and forced to entrap in the concrete mixture and thus may result in a much lighter concrete.

Table 7. Concrete density test results

Mixture no.	Concrete Density (kg/m^3)			
	Fresh concrete		Hardened concrete	
	Value	Percentage decrease	Value	Percentage decrease
Mix-0	2437	0%	2337	0%
Mix-1	2278	7%	2184	7%
Mix-2	2209	9%	2091	11%
Mix-3	2119	13%	2049	12%
Mix-4	2092	14%	2028	13%
Mix-5	2022	17%	1968	16%

Compressive Strength

The compressive strength results of concrete mixtures with and without aluminum byproduct at the ages of 7and 28 days are presented in Table 8. Fig. 7 plots the compressive strength test results at 7 and 28 days *versus* the percentage of aluminum byproduct together with a regression power function that best describes the relation. The compressive strengths of the control mixtures were 23.0 and 31.7MPa at 7 days and 28 days, respectively. The compressive strength of concrete decreased significantly with the addition of ALBP and the maximum reduction was found when ALBP was added at 25% by cement weight. At this addition rate, the compressive strength reduced to 6.3 MPa and 8.4 MPa at the ages of 7 days and 28 days, respectively, which corresponds to 75% reduction in the strength. The trend in the strength reduction is similar for the ages of 7 days and 28 days as reflected

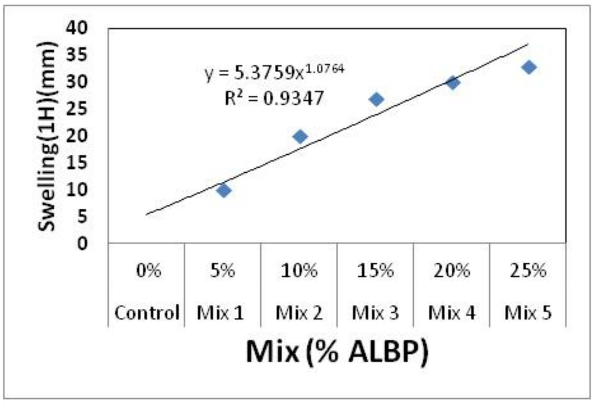

Figure (5): Effect of ALBP % on concrete swelling

in the power function shown in Fig. 7, suggesting that the effect of ALBP on the compressive strength is not sensitive to the age of concrete. The reduction in the strength of concrete is primarily related to the change in chemistry of the cement hydration due to ALBP. The aluminum metal in the alkaline solution reacts with water and produces aluminum hydroxide and hydrogen gas. However, this reaction, although thermodynamically favorable, does not proceed due to the formation of aluminum oxide (Al_2O_3) on the surface of the aluminum particles. For this reaction to proceed, the aluminum oxide layer should be disrupted or removed. As mentioned before, a number of promoters for this kind of reaction include hydroxide, calcium oxides and salts. All of these promoters exist in the cement hydration solution. Thus, this reaction continues and the hydrated alumina layer is removed to the solution. The release of hydrated alumina and aluminum hydroxide to the solution disrupts the balance between the tricalcium aluminates phase (C_3A) and the sulfate (gypsum). This leads to the formation of delayed ettringite, which disrupts the microstructure, thus reducing the strength. One more possible cause of strength reduction is related to the calcium oxide concentration which is in part consumed to promote the reaction with aluminum, thus reducing the amount of calcium silicate hydrates (C_2S and C_3S) that are primarily responsible for the strength of concrete.

Table 8. Cube concrete compressive strength test results

Mixture no.	**Compressive strength (MPa)**			
	7 days		**28 days**	
	Strength	**Percentage decrease**	**Strength**	**Percentage decrease**
Mix-0	23	0	31.7	0
Mix-1	14	39	17.9	44
Mix-2	11.8	49	16.1	49
Mix-3	7.9	66	11.2	65
Mix-4	6.7	71	9	72
Mix-5	6.3	73	8.4	74

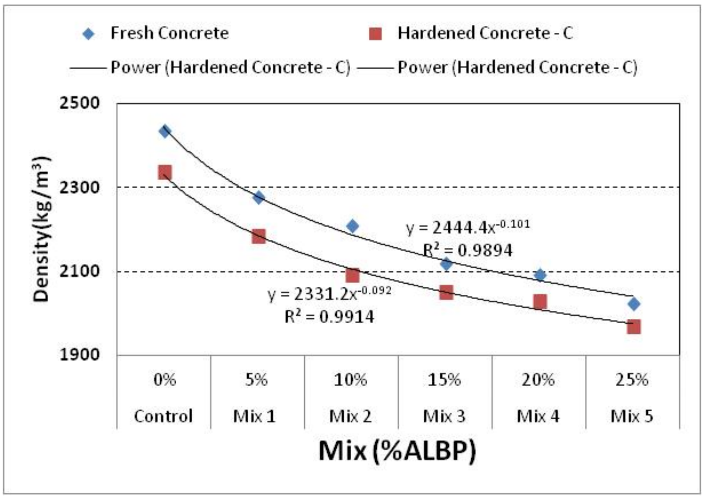

Figure (6): Effect of ALBP % on density of fresh and hardened concretes

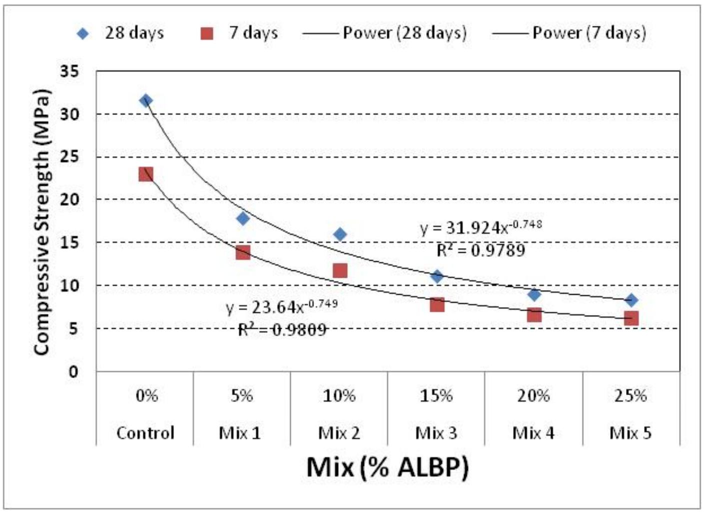

Figure (7): Effect of ALBP % on concrete compressive strength

It should be noted that despite the substantial reduction in the compressive strength of concrete with the increase of ALBP concentration, the remaining strength, even with maximum reduction at 25% of ALBP, is still potentially acceptable for certain applications, such as temporary fillers or lining, as well as for non-bearing walls, blocks and partitions.

Flexural Strength

The results of flexural strength test are summarized in Table 9. Fig. 8 plots the relation between the concrete flexural strength and the percentage of ALBP together with a power function that best describes the relation. The flexural strength of the control mixture was about 4.3MPa at the age of 28 days. The results show that flexural strength of concrete is significantly reduced with the addition of ALBP, with a maximum reduction when ALBP was added at 25% by cement weight. At this addition rate, the flexural strength of concrete at the age of 28 days was 1.3 MPa, which corresponds to 71 % reduction in the strength relative to the control. Similar to the compressive strength results, the flexural strength reduced with the addition of ALBP and the trend is very similar to that for compressive strength as can be seen in Fig 9. Fig.9 also shows that there is a strong linear relation between compressive strength and flexural strength, which means that the effects of ALBP on both compressive and flexural strengths are very similar. As mentioned earlier, the remaining flexural strength may be sufficient for some applications, where weak concrete is required, such as temporary backfills used for covering underground cables and pipes. Furthermore, the flexural strength of around 2.0 MPa can be attractive for non-bearing walls and to produce non-bearing concrete blocks, which can be obtained with ALBP at around 15%.

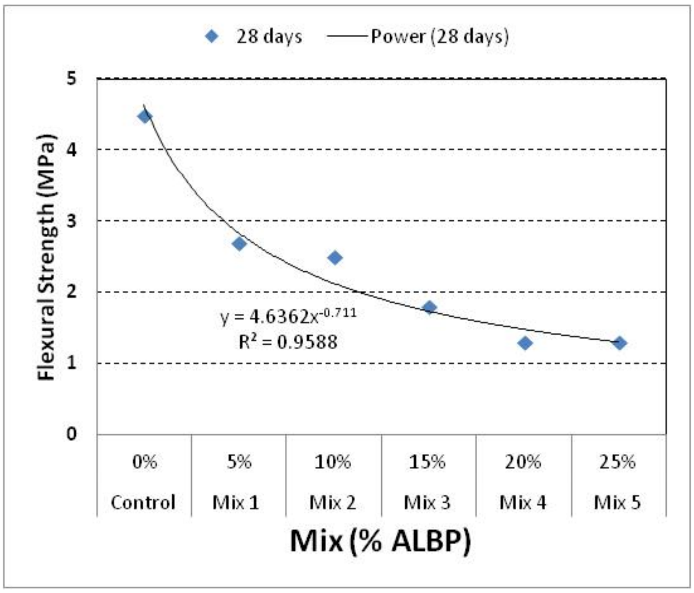

Figure (8): Effect of ALBP % on concrete flexural strength

Table 9. Concrete flexural strength test results

Mixture no.	Flexural strength (MPa)	
	Hardened concrete	
	Strength	Percentage decrease
Mix-0	4.5	0
Mix-1	2.7	40
Mix-2	2.5	44
Mix-3	1.8	60
Mix-4	1.3	71
Mix-5	1.3	71

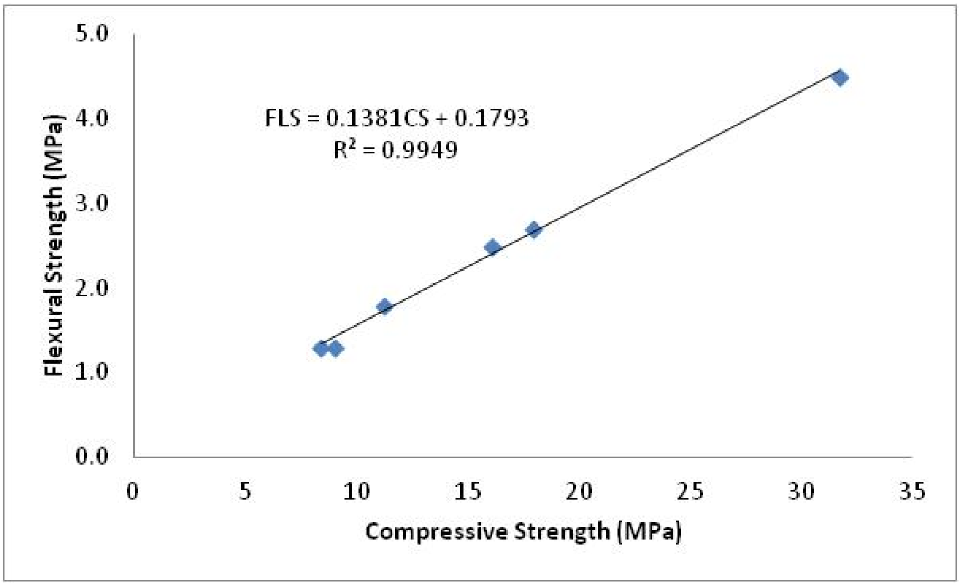

Figure (9): Relation between compressive and flexural strengths of concrete with ALBP

SUMMARY AND CONCLUSIONS

This experimental investigation was performed to evaluate the viability of using aluminum byproduct (waste) in the production of low strength concrete. Aluminum byproduct (ALBP) is obtained from the use of aluminum alloys in engineering applications, primarily in residential building components. The study evaluated the density, swelling, strength and workability properties of concrete mixtures to which aluminum byproduct was added in different proportions (0%, 5%, 10%, 15%, 20% and 25%) by weight of cement. Compression and flexural strength tests were carried out to evaluate the strength properties of hardened concrete. Workability and swelling of fresh concrete were also monitored and recorded. The density of concrete was also measured at the ages of 7 and 28 days. The test results indicate a considerable decrease in workability, compressive strength, flexural strength and density of plain concrete with the addition of ALBP. The results also show that the strength of concrete with ALBP can be sufficient for certain applications, where light and low-strength concrete is required. Overall, the results of this study demonstrate the viability of using ALBP in the production of low strength concrete, where such usage can help toward a more sustainable construction. The following conclusions are drawn from this experimental investigation:

1. Aluminum byproduct addition (up to 25% by cement weight) decreases the compressive and flexural strengths to acceptable levels for certain applications.
2. The addition of 25% aluminum byproduct resulted in almost 17% reduction in concrete density. However, further reduction in density can be obtained if the hydrogen gas is controlled and forced to entrap within the concrete.
3. The inclusion of aluminum in concrete considerably reduces its workability, which necessitates the use of high range water reducing admixtures and perhaps requires modification of the cement chemistry.
4. In the context of sustainable development, the use of aluminum byproduct to produce light and low-strength concrete has been experimentally proven.

5. Also, aluminum waste represents an environmental issue and its management in concrete industry by recycling is a considerable achievement that reduces the need for landfill capacity both on-site and off-site.
6. It can be concluded from this study that with the use of byproduct waste, sustainable concrete construction can be optimized subject to satisfactory performance, in terms of both safety and serviceability, at lower costs and with environmental advantages over ordinary concrete.

REFERENCES

Ahmaruzzaman, M. (2010). “A review on the utilization of fly ash”. Progress in Energy and Combustion Science, 36, 327-363.

Al-Zubaidi, R., Barakat, S., and Altoubat, S. (2013). “Effects of adding brass byproduct on the basic properties of concrete”. Construction and Building Materials, 38, 236-241.

American Concrete Institute, ACI 234R-06. (2006). “Guide for the use of silica fume in concrete”. 63 p.

ASTM. C1240-97b. “Standard specification for silica fume for use as a mineral admixture in hydraulic-cement concrete, mortar and grout”.

Bashar, T., and Ghassan, N. (2008). “Properties of concrete containing mixed color waste recycled glass as sand cement replacement”. Construction and Building Materials, 22 (5), 713-720.

Belitskus, D. (1970). “Reaction of aluminum with sodium hydroxide solution as a source of hydrogen”. J. Electrochem. Soc., 117, 1097-1099.

Goodhue, M., Edil, T.B., and Benson, C.H. (2001). “Interaction of foundry sand with geosynthetics”. Journal of Geotechnical and Geoenvironmental Engineering, 127 (4), 353-362.

Gurpreet Singh, G., and Siddique, R. (2012). “Effect of waste foundry sand (WFS) as partial replacement of sand on the strength ultrasonic pulse velocity and permeability of concrete”. Construction and Building Materials, 26, 416-422.

International Patent Application PCT/CA2006/001300. (2007). “Microporous metals and methods for hydrogen generation from water split reaction”. February 15, 2007; Inventors: Tomasz Troczynski and Edith Czech; Assignee: The University of British Columbia.

International Patent Application PCT/US2006/000180. (2006). “Method and composition for production of hydrogen”. July 6, 2006; Inventor: Jasbir Kaur Anand; Assignee: Hydrogen Power, Inc.

Javed, S., and Lovell, C.W. (1995). “Uses of waste foundry sand in civil engineering”. Transportation Research Record, 1486, 109-113.

Kaur, G., Siddique, R., and Rajor, A. (2012). “Properties of concrete containing fungal treated waste foundry sand”. Construction and Building Materials, 29, 82-87.

Khaloo, A.R., Dehestani, M., and Rahmatabadi, P. (2008). “Mechanical properties of concrete containing a high volume of tire-rubber particles”. Journal of Waste Management, 28 (12), 2472-2482.

Kleven, J.R., Edil, T.B., and Benson, C.H. (2000). “Evaluation of excess foundry system sands for use as subbase material”. In: Proceedings of the 79th Annual Meeting, Transportation Research Board, Washington, DC.CD-Rom, 27.

Limbachiya, M.C., Leelawat, T., and Dhir, R.K. (2000). “Use of recycled concrete aggregate in high-strength concrete”. Materials and Structures, 33, 574-580.

Marroccoli, M., Pace, M.L., Telesca, A., Valenti, G.L., and Montagnaro, F. (2010). “Utilization of coal combustion ashes for the synthesis of ordinary and special cements”. Combustion Science and Technology, 182, 588-599.

Matsunaga, H., Tanishiki, K., and Tsuzimoto, K. (2009). "Environment-friendly block, "ferroform", made from steel slag". JFE Technical Report, No. 13.

Meyer, C. (2009). "The greening of the concrete industry". Cement and Concrete Composites, 31 (8), 601-605.

Naik, T.R., Kraus, R.N., and Siddique, R. (2003). "CLSM containing mixtures of coal ash and a new pozzolanic material". ACI Materials Journal, 100 (3), 208-215.

Pezzi, L., De Lice, P., Vuono, D., Chiappetta, F., and Nastro, A. (2006). "Concrete products with waste materials (bottles, glass, plates)". Materials Science Forum, 1753-1757.

Siddique, R. (2008). "Waste materials and by-products in concrete". XVI, Springer, 414 p.

Siddique, R., Aggarwal, Y., Aggarwal, P., Kadri, E., and Bennacer, R. (2011). "Strength, durability and micro-structural properties of concrete made with used foundry sand (UFS)". Construction and Building Materials, 25, 1916-1925.

Siddique, R., Khatib, J., and Kaur, I. (2008). "Use of recycled plastic in concrete: a review". Waste Management (Elsevier), 28 (10), 1835-1852.

Stockburger, D. et al. (1992). "On-line hydrogen generation from aluminum in an alkaline solution". Proc. Symp. Hydrogen Storage, Electrochem. Soc., 43, 1-44.

Tonnayopas, D., Tekasakul, P., and Jaritgnam, S. (2008). "Effect of rice husk ash on characteristics of lightweight clay brick". In: Technology and Innovation for Sustainable Development Conference, Khon Kaen Univ. 28-29 Jan. 2008, Thailand, 36-39.

U.S. Department of Energy Report. (2008). "Reaction of aluminum with water to produce hydrogen : a study of issues related to the use of aluminum for on-board vehicular hydrogen storage". version 1.

U.S. Patent 6,582,676. (2003). "Hydrogen generation from water split reaction". June 24, 2003; Inventor: Asoke Chandra Das Chaklader; Assignee: The University of British Columbia.

U.S. Patent Application 20060034756. (2006). "Method for generating hydrogen gas utilizing activated aluminum fine particles". February 16, 2006; Inventors: Maseo Watanabe, Ximeng Jiang and Ryuichi Saito; Assignee: Dynax Corporation.

Yüksel, I., and Bilir, T. (2007). "Usage of industrial by-products to produce plain concrete elements". Construction and Building Materials, 21, 686-694.