ISSN 2036 – 9913
Vol. 14 N. 5
September 2023

International Review of Civil Engineering (IRECE)

Contents:

PWP
Praise Worthy Prize

International Review of Civil Engineering (IRECE)

Editor-in-Chief:

Prof. K. M. Liew
Chair Professor of Civil Engineering
Department of Civil and Architectural Engineering
City University of Hong Kong
Hong Kong SAR.

Editorial Board:

Abrams Daniel P.	(U.S.A.)	University of Illinois
Ansal Attila	(Turkey)	Bogaziçi University
Banthia Nemkumar	(Canada)	University of British Columbia
Berke Philip	(U.S.A.)	College of Architecture, Texas A&M University
Cai Steve C. S.	(U.S.A.)	Louisiana State University
Chan Siu-Lai	(Hong Kong)	The Hong Kong Polytechnic University
Dey Subhasish	(India)	Indian Institute of Technology
Dhakal Rajesh P.	(New Zealand)	University of Canterbury
Folić Radomir	(Yugoslavia)	University of Novi Sad
Kappos Andreas	(U.K.)	City, University of London, Dept. of Civil Engineering
Kovler Konstantin	(Israel)	Israel Institute of Technology
Liew Jat Yuen Richard	(Singapore)	National University of Singapore
Mang Herbert	(Austria)	Vienna University of Technology
Sapountzakis Evangelos J.	(Greece)	National Technical University of Athens
Tan Kiang Hwee	(Singapore)	National University of Singapore
Triantafillou Thanasis	(Greece)	University of Patras
Ye J.	(U.K.)	University of Leeds

The ***International Review of Civil Engineering (IRECE)*** is a publication of the **Praise Worthy Prize S.r.l.**.
The Review is published bimonthly, appearing on the last day of January, March, May, July, September, November.

Published and Printed in Italy by **Praise Worthy Prize S.r.l.,** September 30, 2023.

Copyright © 2023 Praise Worthy Prize S.r.l. - All rights reserved.

This journal and the individual contributions contained in it are protected under copyright by **Praise Worthy Prize S.r.l.** and the following terms and conditions apply to their use:
Single photocopies of single articles may be made for personal use as allowed by national copyright laws.
Permission of the Publisher and payment of a fee is required for all other photocopying, including multiple or systematic copying, copying for advertising or promotional purposes, resale and all forms of document delivery. Permission may be sought directly from **Praise Worthy Prize S.r.l.** at the e-mail address:
administration@praiseworthyprize.com

Permission of the Publisher is required to store or use electronically any material contained in this journal, including any article or part of an article. Except as outlined above, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without prior written permission of the Publisher. E-mail address permission request:
administration@praiseworthyprize.com

Responsibility for the contents rests upon the authors and not upon the **Praise Worthy Prize S.r.l.**.
Statement and opinions expressed in the articles and communications are those of the individual contributors and not the statements and opinions of **Praise Worthy Prize S.r.l.**. **Praise Worthy Prize S.r.l.** assumes no responsibility or liability for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained herein.
Praise Worthy Prize S.r.l. expressly disclaims any implied warranties of merchantability or fitness for a particular purpose. If expert assistance is required, the service of a competent professional person should be sought.

REPRINT

Praise Worthy Prize

International Review of Civil Engineering (I.RE.C.E.), Vol. 14, N. 5
ISSN 2036 - 9913 September 2023

Effect of Aluminum Waste on Mortar Thermo-Mechanical Behavior

Mekki Maza[1], Nadia Tebbal[2], Zine El Abidine Rahmouni[1]

Abstract – *This study examines the effect of aluminum (Al) waste additions on the mechanical performance of mortars at high temperatures. The tested mortars have been formulated with different proportions (0%, 2.5%, 5%, 7.5%, and 10%) by weight of sand after being exposed to five temperatures (50 °C, 150 °C, 200 °C, 400 °C, and 600 °C) without imposed load during heating. Workability, setting time of cement, air content, density, mass loss of mortar, thermal conductivity, porosity and mechanicals strength have been examined. The test results indicate a considerable decrease in workability and strength density of the mortar with the addition of Al. This composite has a well thermal conductivity result with 2.5Al and environmentally friendly than ordinary mortar. Further, the experimental data obtained have suggested that the compressive and the flexural tensile strength have been significantly reduced by 90 % in the mortar samples incorporating 10% Al after being exposed to the high temperature of 600 °C. Moreover, the mechanical strength of that mortar has been quite high at the age of 28 days at elevated temperatures in comparison with that measured at 20 °C. The strength of the mortar with Al can be sufficient for some applications where a lightweight, low-strength mortar is required. The use of Al in the production of low-strength concrete can contribute to more sustainable construction.*

***Keywords**: Mechanical Strength, Aluminum Waste, High Temperatures, Porosity, Mortar*

Nomenclature

Al	Aluminum
CPJ CEM II 42.5	Portland cement of strength class 42.5
SP	Superplasticizer
DS	Dune Sand
CS	Crushed Sand
M_f	Fineness modulus
CM	Control Mortar
MA2.5	Mortar with 2.5% Aluminum by weight of sand
MA5	Mortar with 5% Aluminum by weight of sand
MA7.5	Mortar with 7.5% Aluminum by weight of sand
MA10	Mortar with 10% Aluminum by weight of sand
W/C	Water/Cement ratio
Standard ASTM C	Standard American Society for Testing and Materials Cement
NF EN	French Standard being the translation of a European Standard
k	Thermal conductivity coefficient
Q	Heat conducted through the samples
L	Specimen thickness
A	Cross-section area
ΔT	Difference in temperature on both sides of the sample
C_3A	Tricalcium aluminate
C_2S	Dicalcium silicate
C_3S	Tricalcium silicate
CSH	Hydrated Calcium Silicate
RH	Relative Humidity
P	Porosity
Wt	Weight
γ	Absolute density [g/cm^3]
ρ	Bulk gravity [g/cm^3]
ASTM E 119	Standard Test Methods for Fire Tests of Building Construction and Materials

I. Introduction

Aluminum recycling is not a new practice; it dates back to the early 1900s and was widely used during World War II. However, it was a low-profile activity until public awareness was raised [1]. The use of aluminum alloys in engineering applications, primarily in residential building components such as facades, siding, windows, doors, and railings, results in tangible waste that poses an environmental problem and requires management and recycling [2]. Many studies have used aluminum dross in construction applications to replace sand or cement, produce concrete blocks, make aluminate cement, or as filler in asphalt products. Puertas et al. have proved that aluminum dross comprising high alumina could be used as a raw material in the cement production industry [3]. Alzubaidi has investigated the research of recycling aluminum by-product waste in

https://doi.org/10.15866/irece.v14i5.22951

concrete production (ALBP). The test results indicate a decrease in workability, compressive strength, flexural strength, and density of plain concrete with the addition of ALBP [4]. Borhan et al. have studied the thermal properties of cement mortar containing aluminum fine aggregate waste. The results have also revealed that replacing sand with 40 and 60% aluminum filler decreases the reduction rate in compressive strength when the tested samples immediately after being heated to 55°C in an oven [5]. Regarding the thermal conductivity test, the results show a decrease with the increase in aluminum waste content [5]. The effect of temperature on the strength property of concrete mixed with aluminum can waste was conducted by Son in 2004.

The results indicated that the strength of the molds heated to 300 °C decreased by 10% compared to the normal mold, 35% for 600 °C, and 85% for 900 °C. The results also indicated that molds containing more than 5% aluminum could not be formed, their strength was much lower than normal molds, and they deformed greatly with higher centigrade temperatures [6]. The results have showed that AW could be used as a retarder and, therefore, a good material for concreting in hot weather [7]. Concrete can deteriorate for various reasons, and concrete damage often results from a combination of factors. Very little research has been conducted to investigate the influence of various material parameters on the durability performance of concrete or mortar mixtures, including the effects of Aluminum Fines (AF) on freeze-thaw resistance. The freeze resistance of concrete made with durable aggregates is determined by the ability of the air-vacuum system to prevent the development of destructive pressures due to freezing and the associated moisture movement into the concrete pores [8]. The use of a superplasticizer admixture in concrete has resulted in a significant increase in slump and flow of the mix but has reduced the air content of the mix and increased its density. With tilting the air-entraining admixture, the mix’s slump, flow, and air content have increased, but the density has decreased [9].

According to [10] aluminum industry flowchart, the hydraulic activity of aluminum drosses allows it to be used as a cement hardening agent without clinker, with a suitable activator and mix design providing quite usable mechanical properties and high resistance to water and sulfate attack. However, the importance of aluminum residues has not been limited to improving certain properties of concrete but has also surpassed it to increasing the bond between lateralized concrete and steel [11]. The use of nanomaterial has become a popular way to improve the performance of cement-based composites. At the same time, ultra-high-strength concreteis increasingly being used. [12] has studied ultra-high strength cement-based composites designed with aluminum oxide nano-fibers. This research has demonstrated that using small amounts of aluminum oxide nanofibers in an oil-well cement-based mortar could provide compressive strength close to 200 MPa and help meet the benchmark for ultra-high-strength cement-based composites. [13], [14] have conducted a study on concrete produced using recycled aluminum dross for hot weather concreting conditions using mixing and testing as recommended procedures by relevant codes. The results have indicated that the initial setting time of recycled aluminum dross concrete has been extended by approximately 30 min at the 20% replacement level. This recycled aluminum foam concrete property is suitable for hot weather concreting conditions. Aadi et al. [15] have studied the use the natural sand replaced by Aluminum Wastes (AW) to produce green cement mortar for different construction applications. Their results have showed that the mortar contained up to 5% of AW can be used for structural application. The AW ratio in the range of 15-30% can be suitable for lightweight mortar for nonstructural applications. According to a number of researchers, the categorization of concrete is often based on its specific gravity and compressive strength [16]-[18].

Mohammadyan-Yasouj [19] has showed that the using Nano-Alumina (NA) decreases compressive strength of samples in the ambient temperature, but improves their compressive strength after ten minutes heating under the target temperature of up to 200 °C. Studies on the effect of aluminum waste on the thermo-mechanical properties of mortar are scarce. To this end, this study aims to evaluate the behavior of fresh and hardened mortar manufactured by adding industrial by-product (Al) waste in different proportions. Two critical aspects of mortar durability performance have been investigated: formulated mortar rheology and fire resistance. The experimental parameters have included the cement type and fine aluminum amount. Different types of mortar M have been made from materials and products manufactured in Algeria: Portland Artificial CPJ CEM II 42.5 cement, Superplasticizer (SP), Aluminum waste (Al) with binary sand mixtures. In this study, binary sand mixture aggregates have been used: DS (Dune Sand) and CS (Crushed Sand). The goals of this experimental work have been to investigate the following aspects:

- The possibility of reusing aluminum waste in mortar and concrete mixes as a partial replacement of fine aggregates in order to reduce the environment impact resulting from industrial waste disposal;
- The impact of solid wastes (aluminum waste) on the physical properties of binary sand prepared (i.e., density, porosity, fineness modulus, particle size distribution and water absorption) and mechanical response (i.e., setting time and air content, flexural, tensile and compressive strengths, Influence of temperature and heating time and mass loss) of the mortars made with binary sand mixtures.

In order to protect the environment from industrial waste and to explain the importance of reusing aluminum waste in mortar in particular and innovative concrete in general, the paper has been divided into different sections. The first part deals with all recent studies regarding the valuation of industrial residues in the field of cement materials, especially aluminum residues. The second section, “Materials and Methods,” deals with the materials used, their chemical and physical properties, and illustrates methodology of mixing all mixtures.

Visual evaluations of all formed mortars before and after hardening, as well as exposure to high temperatures are discussed in the following section. Discussion and conclusions are summarized at the end of the paper.

II. Materials and Methods

II.1. Materials

Portland cement: in this experimental study, the type CEMII 42.5 from Hammam Dalâa local factory has been used. It has a Blaine-specific surface area of 3,850 cm^2/g and a density of 3.2. Table I lists the chemical compositions of the cement.

Sand: a mixture of 1/3 dune and 2/3 crushed sand [20] has been used for the preparation of the various study mortars with fineness modulus (M_f of 2.63). The natural fine aggregates (DS) used have been dune sand with a particle size between 0.08 mm and 5 mm. This natural sand has been collected in the region of Boussâada (250 km east of Algiers). The particle size analysis has been performed according to the European standard (NF EN 933-1) [20].

Crushed Fine Aggregate (CS): in this study, the fine aggregate manufactured used have been crushed sand generated from the quarry waste (calcareous crushed sand). Figs. 1 and 2 show the particle size distribution of the sand used. Table II presents the physical properties of dune sand, crushed sand, and aluminum waste.

TABLE I
THE CHEMICAL AND MINERALOGICAL PROPERTIES OF CEMENT

Chemical composition (%)							
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O
17.8	61.2	4.4	2.6	1.8	2.6	0.1	0.6
Mineralogical compositions (%)							
C_3S	C_2S	C_3A	C_4AF	Gypse			
45.8	14.3	2.6	10	19.8			

TABLE II
PHYSICAL PROPERTIES OF DUNE SAND, CRUSHED SAND, AND ALUMINUM WASTE

Physical properties	DS	CS	Al
Fineness modulus	1.77	3.16	5.09
Absolute density (g/cm^3)	2.65	2.70	5.45
Apparent density (g/cm^3)	1.52	1.49	2.07
Porosity (%)	42	44	62.01

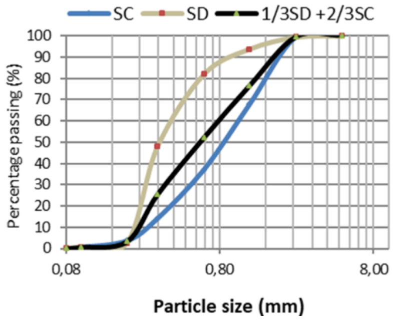


Fig. 1. Particle size distribution of sand used

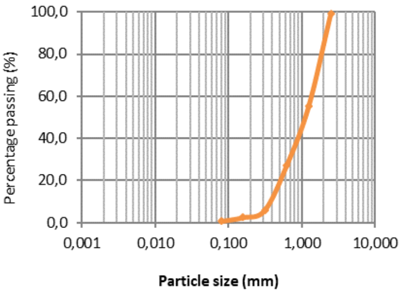


Fig. 2. Particle size distribution of Al waste

Aluminum waste has been obtained from the remains of aluminum windows and doors manufacturing aluminum. The substitution ratios of aluminum waste in mortar have been 0, 2.5, 5, 7.5, and 10% by volume of sand. It has been screened on the sieve number (0/3 mm) to be close to the sizes of sand (Fig. 2). Table III summarizes the chemical composition of Al used. Tap water from the civil engineering laboratory has been used for mixing throughout the study.

II.2. Mix Design

Table IV lists the proportions of the mortar mixes.

Five mortar mixes have been prepared for the experimental stage. The Control Mix (CM) has included only Portland cement as a binder, i.e., it has not contained aluminum. The mixes had different aluminum contents of 2.5, 5, 7.5, and 10% by weight of sand and have been named MA2.5, MA5, MA7.5, and MA10, respectively. The total amounts of cementitious material content and slump value have been recorded consistently for all mixes. Since the slump value has been kept constant, water has been gradually added to the mixes, and thus the water/cement ratio (W/C) has not been kept constant and has changed from 0.5 to 0.6 (Standard ASTM C 305-99) [21]. The fresh mortar mixtures have been prepared in several steps.

TABLE III
CHEMICAL COMPOSITION OF ALUMINUM WASTE

Elements	(%)
S_i	.516
Fe	.335
Cu	.0771
Mn	.094
Mg	.327
Zn	.958
Ti	.0197
Cr	.0013
Ni	.0043
Pb	.0063
Sn	.007
Na	.0068
Al	98.51

TABLE IV
MIXTURE PROPORTIONS

Mix Design	Sand (kg)	AL (kg)	Water (kg)	W/C	Cement (kg)
MC	1.350	0	225	0.50	0.450
MA2	1.316	0.034	270	0.60	
MA5	1.283	0.06750	270		
MA7.5	1.249	0.10125	270		
MA10	1.215	0.135	270		

The sand and cement to be tested have been mixed with water in the following proportions: 450 ± 2 g of cement and 1350 ± 5 g of sand. The mixing procedure has been determined by verifying the evolution of the slump flow as a function of mixing time. Initially, the dry materials have been mixed for 15 s.

Then, water has been added at a mixing speed of 1.6 m/s, and the superplasticizer has been manually added to the mixture within 20 s.

Setting time and air content: the testing of the initial and final experimental protocol setting has been consistent with the recommendations of the European Standards NF EN – (196- 3) and NF EN (197- 1) [22], [23]. The mortar air content has been determined following Standard ASTM C 185.

Density: the density ρ of the mortars has been measured according to the Standard NF EN 196-1 [24].

Compressive and bending tensile strength: the mechanical resistance has been tested according to Standard NF-EN 196-1 [24]. For 24 h before demolding the mortar specimens, 4 cm × 4 cm × 16 cm, have been kept in a wet place at a temperature of 20 °C and 95% Relative Humidity (RH) during 24 hours. Then they have been kept under water until the age of testing. After 28 days, they have been tested in a three-point bending machine.

Porosity: the water-accessible porosity protocol is in accordance with the AFREM group recommendations [25]. Porosity has been calculated from the absolute and bulk density values by using Eq. (1):

$$P(\%) = \left(1 - \frac{\rho}{\gamma}\right)100 \tag{1}$$

where P is the porosity that corresponds to the pore and void content of the samples (wt. %), γ is the absolute density (g/cm^3), and ρ is the bulk gravity (g/cm^3).

Heating: after 28 days, specimens with dimensions 4 cm × 4 cm ×16 cm have been dried in an oven at 100 °C until stabilization of their mass. All specimens have been subjected to high temperatures (200 °C, 400 °C, 600 °C, and 900 °C) according to the Standard ASTM E 119-00 [26].

Thermal conductivity: the thermal conductivity coefficient has been tested by using the steady-state guarded hot plate method ASTM C 177-19 [27]. The thermal conductivity (k) has been calculated by using Eq. (2):

$$K = QL/A\Delta T \tag{2}$$

where Q is the amount of heat conducted through the samples, L is the specimen thickness, A is the cross-section area, and ΔT is the difference in temperature on both sides of the sample.

III. Results and Discussion

III.1. Workability of Fresh Concrete

Figure 3 presents the slump results for all mortar mixtures. The slump value for the control mortar has been 6 cm. while those for MA5 to MA10 have been observed at 5.5, 5.3, 5, and 4.8 cm. respectively. The addition of Al decreases the mortar slumps compared to the control, which can be attributed to two reasons. The mechanical reason concerns the varying sizes of the aluminum particles that consume part of the volume of the paste to coat it and mechanically hinder the mortar flow. The chemical reason is the reaction between metallic aluminum and water in the alkaline medium, forming aluminum hydroxide and releasing hydrogen gas. The aluminum hydroxide passes into the solution and disturbs the alumina-sulfate balance ratio in the mortar, disturbing the setting properties and forming compounds, reducing slump and potentially important for rapid setting as seen at the high aluminum dosage of 10%. The addition of aluminum waste in the 5% to 7.5% range results in similar reductions in a slump. Beyond this range, aluminum waste significantly reduces the mortar slump, and the mortar no longer becomes workable [28].

III.2. Setting Time of Cement

Figure 4 shows the setting time properties for all mixes. It can be seen that when the aluminum waste reaches 10% of the sand replacement, the Al content increases hardening and reduces setting time. A higher surface area of nanoparticles in the aluminum waste during the hydration process can be explained as a major reason for the extension or shortening of the setting time, allowing for greater absorption of liquids [29].

III.3. Air Content

Figures 5 show the effect of Al on-air content and mortar swelling for the five mortar mixes containing 0, 2.5, 5, 7.5, and 10% Al. The measurements have been taken after casting. The swelling test has been performed after the mortar sample dimensions have been stabilized.

From the results obtained, it can be seen that an increasing amount of aluminum waste reduces the setting time of the mortar.

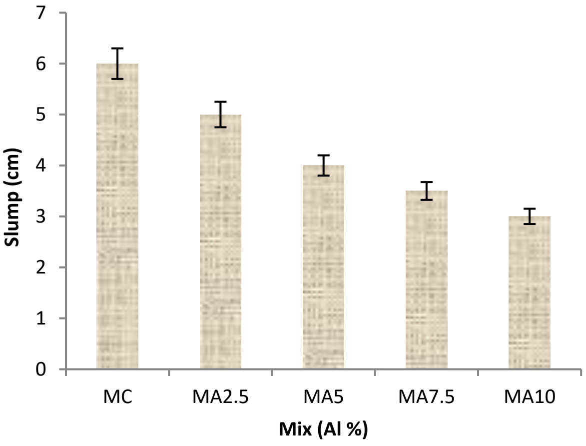


Fig. 3. Effect of Al % on concrete slump values

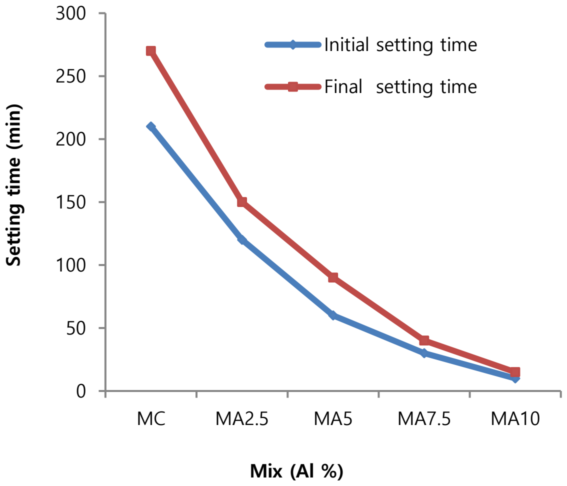


Fig. 4. Effect of Al % on mortar setting time values

The high porosity or trapped air content can be explained by the high absorption capacity of aluminum waste (Fig. 5(a)). The expansion of the mortar samples for the five mortar mixtures containing 0, 2.5, 5. 7.5 and 10% Al has been measured after casting (Fig. 5(b)). The expansion test has been performed after the dimensions of the prismatic and cylindrical mortar specimens had stabilized.

The growth of the specimen height has been measured 30 min after pouring. For all mortars, the volume increases with increasing Al % in the mixtures.

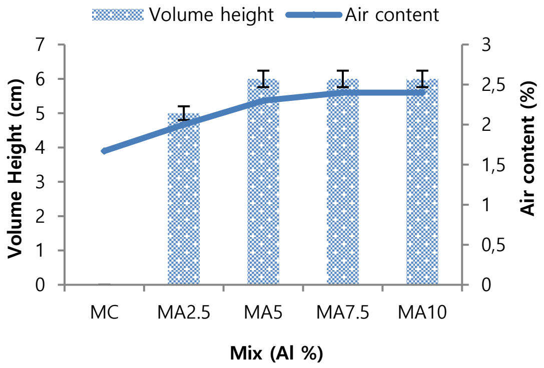
The maximum expansion value of all mixtures has been 6 cm for MA10. The expansion is attributed to hydrolysis of Al and Al_2O_3 since the medium is alkaline to form the voluminous $Al(OH)_3$, in which the hydrogen gas creates bubbles that try to escape to the surface, thus, creating voids and increasing the volume of mortar.

Cesar (2002) explained this expansion reaction between alumina and cement hydrates that can form early ettringite that is expansive, thus increasing the volume of mortar, similar to the case when expansive cement is used in a mortar [30].

III.4. Mortar Density

Figure 6 shows the density values of the hardened mortar. It can be noted that the mortar density decreases with the addition of Al. The maximum reduction has been found at around 27% when Al has been added at 10% of the sand weight. Most researches have attributed the decrease in density to the presence of a reaction between the metallic aluminum and the alkaline solution of the cement paste. The increase in the volume corresponding to a reduction in mortar density is due to the release of hydrogen gas and the formation of expansive products from the exothermic reaction between aluminum and cement hydrates [31] according to the following endothermic reaction:

$$2\text{Al} + 3\text{Ca}\,(\text{OH})_2 \rightarrow 3(\text{CaO})\text{Al}_2\text{O}_3 + 3\text{H}_2 \qquad (3)$$



(a) Effect of Al % on mortar air content

(b) Samples after expansion

Figs. 5. (a) Effect of Al% on mortar air content and (b) volume height values

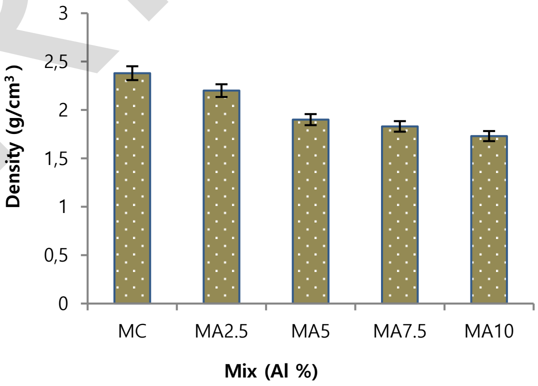


Fig. 6. Effect of Al % on mortar density

III.5. Effect of Aluminum Waste on the Porosity

Figure 7 shows the results of the porosity tests. The percentages of porosity in MC, MA2.5, MA5, MA7.5 and MA10 have been 8, 9, 11.75, 13.50, and 16.44%, respectively. In the short term (28 days), the MC mortar has low porosity than the MA mortar. The difference between the physical properties of each type of fine aggregate is the cause of the variance observed between the porosities studied. In addition, it can be noticed that partial replacement of sand with aluminum aggregate (2.5, 5, 7.5 and 10% Al combined) increases porosity at 28 days. However, at 10% aluminum waste, there is a significant increase in porosity (for MA10 mortar, the increase in porosity is 50%) due to the fine aluminum aggregate's high absorption capacity and high porosity.

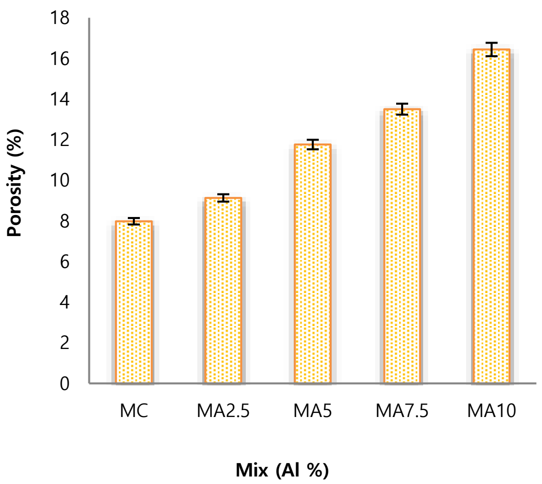


Fig. 7. Effect of Al % on mortar porosity

III.6. Effect of Aluminum Waste on the Mechanical Strengths

Figure 8 shows the mortar compressive and flexural strength results at 28 days. It can be noted that the compressive strength of the mixtures decreases with the addition of Al, and the maximum reduction has been recorded when Al has been added at 10% of the sand weight.

The strength of MA2.5 has been up to 16 MPa, while the resistance of MA10 has been only 4.55 MPa, which is proved by the rapid crushing of the samples (Fig. 9).

Therefore, it can be concluded that replacing sand with high levels of aluminum waste is not suitable (Watanabe et al. 2006). Figure 10 shows the aluminum-water reaction. Hydrogen gas and aluminum hydroxide have been produced in the chemical reaction between water and metallic aluminum. The release of hydrated alumina and aluminum hydroxide into the solution disrupts the equilibrium between the tricalcium aluminate (C_3A) and sulfate (gypsum) phase [32]. This leads to the formation of delayed ettringite, which disturbs the microstructure, and reduces the concentration of calcium oxide partially consumed to enhance the reaction with aluminum. Thus, the decrease in resistance is explained by the reduction in the amount of calcium silicate hydrates (C_2S and C_3S), which is mainly responsible for the strength of the mortar [33]. The flexural strength of the control mix has been approximately 5.65 MPa at 28 days of age. At this rate of addition, the flexural strength of the mortar at 28 days has been 1.12 MPa, which corresponds to an 80% decrease in strength compared to the control. Coupled with the compressive strength results, the flexural strength has decreased with adding Al, and the trend is similar to the compressive strength.

Recent research suggests some uses where residual flexural strength of about 2.0 MPa may be of interest for non-load-bearing walls and to produce non-load-bearing concrete blocks, which can be achieved with Al at about 10% [32], [33].

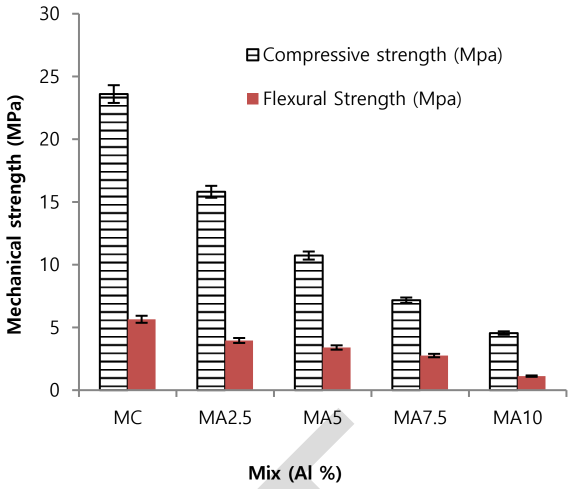


Fig. 8. Effect of aluminum waste on the mechanical strengths

Fig. 9. Mortar samples broken during mechanical testing

Fig. 10. Aluminum-water reaction

III.7. Influence of Temperature and Heating Time on Mortar Mass Loss

Figure 11 shows the effect of high temperatures on the mass loss of MC, MA2.5, MA5, MA7.5, and MA10. The weights of the specimens have been evaluated in four distinct temperature ranges: 100, 150, 200, 400, and 600 °C. The other three samples have been placed in an oven with a temperature up to 55 °C (the duration of the peak period in Ouargla. Algeria).

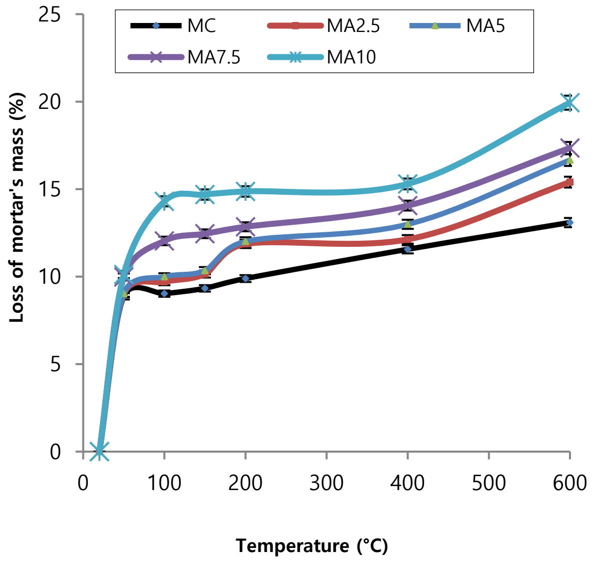


Fig. 11. Evolution of mass loss related to temperature

The mass loss has increased for air-cooled samples with increasing temperature for all samples subjected to high temperature. In the range of 50-150 °C, MA10 mortar shows the largest decrease. At the same time, the control mortar and MA2.5 have showed the minimum value. MA7.5 and MA5 mortars have showed higher weight loss than MA2.5 and lower than MA10. The weight loss in this temperature range is generally attributed to moisture evaporation from the sample surface to the atmosphere. When the temperature rises from 150 to 400 °C, most of the water in each concrete specimen evaporates.

The increase is almost linear up to a temperature of 600 °C. This result can be explained by the evaporation of water and the gradual dehydration of the CSH gel [34], [35]. Figure 12 shows that increasing aluminum increases void formation due to gas release, reducing the mortar mass at high temperatures. The mass loss is minimal for mortars (MA2.5) up to about 600 °C.

However, the aggregate's nature significantly influences the mass loss in mortars above 600 °C. In the case of aluminum scrap mortar, the mass loss is not significant above 600 °C compared to MC mortar. Many researchers have confirmed that the higher percentage of mass loss in concrete/mortar is attributed to the dissociation of dolomite in the carbonate aggregate at around 600 °C.

The increase in porosity with increasing temperature and pore evolution is contaminated due to product deterioration in the maximum degrees of temperature [36].

III.8. Results of Compressive Strength After Cooling

Figure 13 shows the compressive strength of mortars at 20 ± 5 °C and after exposure to 200, 400, and 600 °C.

It can be noted that the strength decreases with increasing temperatures.

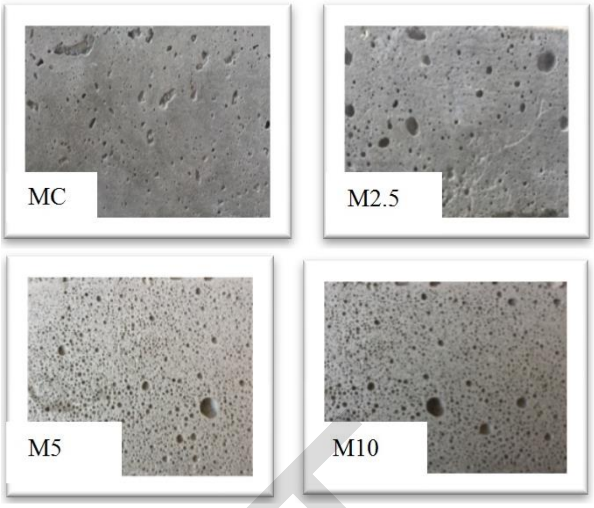


Fig. 12. Porous texture of mortars

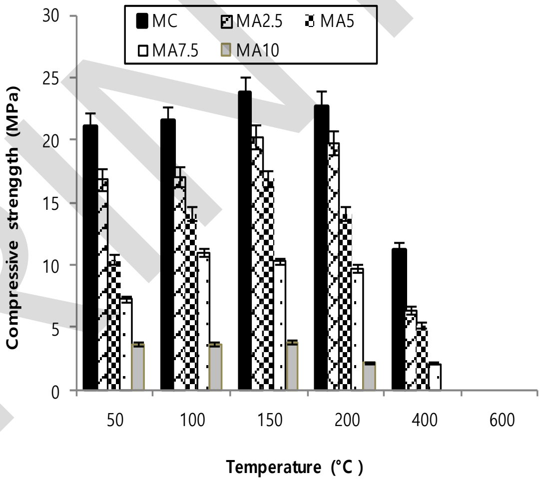


Fig. 13. Compressive strength after cooling

Mortars exposed to the influence of high temperatures lose a significant portion of their strength value. The loss of compressive strength becomes evident at 150 °C with a strong recovery of 12.5, 17, and 38.5% for MC, MA2.5, and MA5 mortars, respectively. These gains at 150 °C to 200 °C are attributed to the increase in forces between the gel particles due to the removal of water content [37]. When the temperature increases above 150 °C, the strength of the mortars is greatly reduced due to the dehydration of the surface water content. Between 400 and 600 °C, the free water content evaporates quickly and causes internal cracking due to the steam effect, which explains the decrease in resistance. Severe strength losses have occurred in all MC, MA2.5, MA5, and MA7.5 mortars. In this range, the cement paste contracts while the aggregates expand. Thus, the transition zone and the bond between the aggregates and the paste are weakened. MA10 mortar has showed the greatest loss of strength, approximately 80%, 86%, and 100% of its unheated strength when heated to 200, 400, and 600 °C, respectively. $Ca(OH)_2$ decomposes between 400 and 600 °C [38], [39]. For 400 °C, a strong compressive loss for MA10 specimens has been tested.

All mortars (MC, MA2.5, MA5, MA7.5) have lost 100 % of their resistance at 600 °C. It can be noted that the great losses of resistance for all mortars are due to the porous microstructure of mortars, which has caused the accumulation of high internal pressure attributed to the transition of water vapor from the intercalated water.

Thus, this process causes severe deterioration and strength losses in the mortar after exposure to high temperatures. It appears that the amount of aluminum waste does not significantly influence the compressive strength between 400 °C and 600 °C. However, in the range of 50 °C and 200 °C, 2.5% to 5% Al significantly affects the compressive strength.

III.9. Thermal Conductivity

Figure 14 shows the thermal conductivity results for MC, MA2.5, MA5, MA7.5, and MA10 mortars with partial sand replacement. For mortars without Al, the thermal conductivity has been 1.93 ± 2 W/mK. However, the thermal conductivity of mortars with Al has been generally in the lower range of about 1.9 -1.85 W/mK.

The thermal conductivity values obtained are in good agreement with those previously reported by Borhan et al. [40], [41]. The decrease in thermal conductivity has been approximately 15.54 to 41.45%. This minor conductivity of the MA mixed mortar indicates that the presence of aluminum content has a positive effect on decreasing the capacity of the heat transmitted during the thickness of the samples. The low results of the thermal conductivity coefficient in the mortar can be explained by an increase in the aluminum content, which leads to an increase in the formation of voids due to gas release.

As a result, this mortar has a better insulating competence than the normal mortar. According to Figure 14, the substitution of sand for aluminum waste of more than 10% generally reduced the thermal conductivity.

The only exception has been the case of MA2.5 mortar in the mortar containing 2.5% Al, which may be due to the filling of voids in the binder matrix with the small amount of aluminum waste, resulting in high thermal conductivity.

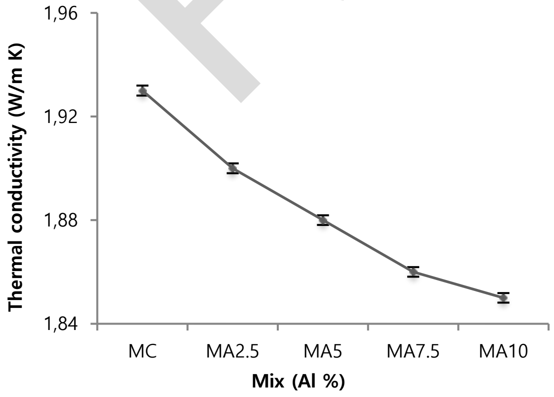


Fig. 14. Thermal conductivity of mortars without Al and with 2.5, 5. 7.5, and 10% Al

For the other mortars, the reduction in thermal conductivity with the addition of Al is due to the introduction of voids in the mortars, resulting in increased porosity and decreased compressive strength of the mortars [42], [43].

IV. Conclusion

This study has investigated the mechanical and thermal behavior of a new type of mortar obtained by adding aluminum waste. In addition, the effect of the severe environmental conditions of the Algerian desert on the durability properties of the added aluminum waste mortar has been studied. The results obtained encourage the mixing of aluminum residues in the mortar, which greatly contributed to its workability. In addition, the cement paste’s initial and final setting time increases with the incorporation of the aluminum waste mixture, and up 10% of the weight of the sand, the compressive and flexural strengths reduces to acceptable levels for certain applications (building subflooring, block, and precast panel manufacturing). Furthermore, the higher percentage of Al waste replacement is, the more air is trapped and the higher the porosity is, which negatively affects the mechanical strength. In the context of thermal conductivity, the results of laboratory experiments have demonstrated that replacing part of the sand in a mortar of less than 10% had a positive effect on increasing thermal conductivity. With these encouraging values, the material developed in this research using local materials such as sand dunes, very abundant in the Sahara of Algeria, shows that it is possible to consider this type of concrete for the production of lightweight concrete that adapts very well to the hot and arid environment of our region given its very acceptable characteristics, which allow its classification in the margin of lightweight concretes. In future studies, it is recommended adding Al waste to environmentally friendly geopolymer activation solutions in order to reduce the geopolymer preparation time and induce significant changes in porosity and it is also possible to recommend the production of cellular concrete.

Acknowledgements

The authors acknowledge the technical support of the Geomaterials Development Laboratory of the Department of Civil Engineering. This research was supported by the“DGRSDT-MESR” of Algeria.

References

[1] M.E. Schlesinger, *Aluminum recycling*. CRC press, 2013. https://doi.org/10.1201/9781420006247 .

[2] C. Meyer, The greening of the concrete industry. *Cement and concrete composites*, 31(8), 601-605, (2009). doi: https://doi.org/10.1016/j.cemconcomp.2008.12.010

[3] F. Puertas, M. T. Blanco-Varela, T. Vazquez, Behaviour of cement mortars containing an industrial waste from aluminium refining: Stability in Ca (OH) 2 solutions. *Cement and Concrete*

research, 29(10), 1673-1680, 1999.
doi: https://doi.org/10.1016/S0008-8846(99)00157-X.

[4] R. Alzubaidi, Recycling of Aluminum Byproduct waste in concrete production. *Jordan Journal of civil engineering*, 11(1), 2017.

[5] T. M Borhan, H. Janna, Thermal properties of cement mortar containing waste aluminium fine aggregate. *Journal of Kerbala University*, 12, 193-200, 2016.

[6] Son, Ki Sang and Lee, Soo Kyung, 2004. Temperature Effect Of Concrete Strength Property Mixing With Waste Aluminum Drink Can. *AOFST 6*.

[7] A. U. Elinwa, E. Mbadike, The use of aluminum waste for concrete production. *Journal of Asian Architecture and Building Engineering*, 10(1), 217-220, 2011.
doi: https://doi.org/10.3130/jaabe.10.217

[8] D. J. Janssen, M. B. Snyder, *Resistance of concrete to freezing and thawing* (No. SHRP-C-391). 1994.

[9] A. Klovas, M. Daukšys, The Influence of Admixtures on the Technological Properties of Fresh Concrete Mixture, *Materials Science*, 21(4), 595-600 (2015).
doi: http://dx.doi.org/10.5755/j01.ms.21.4.5170.

[10] J. Sun, Y. Yang, Performance of New Non-Clinker Aluminum Dross Cement Curing Agent. *3rd International Conference on New Energy and Renewable Resources (ICNERR 2018)*.

[11] O. M. Ofuyatan, A. A. Ivoke, A. M. Olowofoyeku, A. Adesina, J. Oluwafemi,. Effect of waste aluminium shavings on the bond characteristics of laterized concrete. *Advances in materials Research*, 8(1), 25-36, 2019.
doi: https://doi.org/10.12989/amr.2019.8.1.025

[12] S. Muzenski, I. Flores-Vivian, K. Sobolev, Ultra-high strength cement-based composites designed with aluminum oxide nano-fibers. *Construction and Building Materials*, 220, 177-186, 2019.
doi: https://doi.org/10.1016/j.conbuildmat.2019.05.175

[13] G. Mailar, B. M. Sreedhara, D. S. Manu, P. Hiremath, K. Jayakesh, Investigation of concrete produced using recycled aluminium dross for hot weather concreting conditions. *Resource-Efficient Technologies*, 2(2), 68-80, 2016.
doi: https://doi.org/10.1016/j.reffit.2016.06.006

[14] N. Tebbal, Z. E. A. Rahmouni, Influence of local sand on the physicomechanical comportment and durability of high performance concrete. *Advances in Civil Engineering*, 2016.
doi: https://doi.org/10.1155/2016/3897064

[15] A. S. Aadi, T. K. M. Ali, R. A. A. Ali, M. M. Salman, The mechanical properties of green mortar contained aluminum wastes as substitution of sand. *Materials Today: Proceedings*, 2021, vol. 42, p. 3002-3009.
doi: https://doi.org/10.1016/j.matpr.2020.12.812

[16] A. Meshram, R. Jha, S. Varghese, Towards recycling: Understanding the modern approach to recover waste aluminium dross. *Materials Today: Proceedings*, 2021, vol. 46, p. 1487-1491.
doi: https://doi.org/10.1016/j.matpr.2020.11.423

[17] A. Paktiawal, M. Alam, An experimental study on effect of aluminum composite panel waste on performance of cement concrete. *Ain Shams Engineering Journal*, 2021, vol. 12, no 1, p. 83-98.
doi: https://doi.org/10.1016/j.asej.2020.07.024.

[18] I. A.Channa, A. Saand, Mechanical behavior of concrete reinforced with waste aluminium strips. *Civil Engineering Journal*, 2021, vol. 7, no 7, p. 1169-1182.
doi: http://dx.doi.org/10.28991/cej-2021-03091718

[19] S. E. Mohammadyan-Yasouj, N. Heidari, H. Shokravi, Influence of waste alumina powder on self-compacting concrete resistance under elevated temperature. *Journal of Building Engineering*, 2021, vol. 41, p. 102360.
doi: https://doi.org/10.1016/j.jobe.2021.102360

[20] NF EN 933-1, Tests to determine the geometric characteristics of aggregates - Part 1: Determination of granularity - Particle size analysis by sieving. 2006.
https://www.boutique.afnor.org/fr-fr/norme/nf-en-9331/essais-pour-determiner-les-caracteristiques-geometriques-des-granulats-part/fa027452/10638

[21] A STM C 305-99, Standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency, ASTM Book of Standards 04.01.
https://www.astm.org/standards/c305

[22] NF EN – (196- 3). Methods of testing cements - Part 3: Determination of setting time and stability.
https://www.boutique.afnor.org/fr-fr/norme/nf-en-1963/methodes-dessai-des-ciments-partie-3-determination-du-temps-de-prise-et-de-/fa186374/79422

[23] NF EN – (197–1). Cement – Part 1: composition , specification and conformity criteria for common cements.
https://www.boutique.afnor.org/fr-fr/norme/nf-en-1971/ciment-partie-1-composition-specifications-et-criteres-de-conformite-des-ci/fa149898/1234

[24] NF EN 196-1. Cement test methods - Part 1: determination of strengths.
https://www.boutique.afnor.org/fr-fr/norme/nf-en-1961/methodes-dessais-des-ciments-partie-1-determination-des-resistances/fa184622/57803

[25] AFPC-AFREM Durability of concrete working group . Recommended test methods for measuring the parameters associated to durability. *Proceedings of the Technical Days AFPC-AFREM: Concrete Durability*. Dec. 11-12. 1998.
https://www.worldcat.org/title/compte-rendu-des-journees-techniques-de-l-afpc-afrem-groupe-de-travail-durabilite-des-betons-methodes-recommandees-pour-la-mesure-des-grandeurs-associees-a-la-durabilite-11-et-12-decembre-1997-toulouse/oclc/468247734

[26] ASTM E 119-00 a . Standard test methods for fire test of building construction and materials. American National Standards Institute. Committee E05; 2000.
https://www.docsity.com/pt/astm-e-119-standart-test-methods-for-fire-tests-of-building-construction-and-materials/4801759/

[27] ASTM C177 – 19. Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus.
https://webstore.ansi.org/Standards/ASTM/astmc17719

[28] S. Barzgar, B. Lothenbach, M. Tarik, A. Di Giacomo, C. Ludwig, The effect of sodium hydroxide on Al uptake by calcium silicate hydrates (CSH). *Journal of colloid and interface science*, 572, 246-256. (2020).
doi: https://doi.org/10.1016/j.jcis.2020.03.057

[29] A. Barzegar, T. Ghaffari, A. Parizad, Effect of incorporating aluminum oxide nanoparticles on thermal conduction and flexural strength of acrylic resins. *Dental Research Journal*, 2022, vol. 19. p. 1-6.

[30] E. L'Hôpital, B.Lothenbach , G. Le Saout, D.Kulik, K. Scrivener, Incorporation of aluminium in calcium-silicate-hydrates. *Cement and Concrete Research*, 75, 91-103. (2015).
doi: https://doi.org/10.1016/j.cemconres.2015.04.007

[31] E. G. D.Araújo, J. A. S. Tenório, Cellular concrete with addition of aluminum recycled foil powders. In *Materials science forum* (Vol. 498, pp. 198-204). Trans Tech Publications Ltd. (2005).

[32] N. Tebbal, Z. E. A. Rahmouni, Valorization of aluminum waste on the Mechanical Performance of mortar subjected to cycles of freeze-thaw. *Procedia Computer Science*, 158, 1114-1121. (2019).
doi: https://doi.org/10.1016/j.procs.2019.09.234

[33] S.Schreck, J. Lundquist, W. Shaw, (.*US Department of Energy Workshop Report-Research Needs for Wind Resource Characterization* (No. NREL/TP-500-43521). 2008. National Renewable Energy Lab. (NREL), Golden, CO (United States).
https://www.nrel.gov/docs/fy08osti/43521.pdf

[34] N. Tebbal, Z.Rahmouni, M. Maza, Combined effect of silica fume and additive on the behavior of high performance concretes subjected to high temperatures. *Mining Science*, vol. 24, 2017, 129−145.
doi: https://doi.org/10.5277/msc172408

[35] M. Belouadah , Z. E. A. Rahmouni, N.Tebbal, Effects of glass powder on the characteristics of concrete subjected to high temperatures. *Advances in concrete construction*, 2018, vol. 6, no 3, p. 311.
doi: https://doi.org/10.12989/acc.2018.6.3.311

[36] L. Zuda, P. Rovnaník, P. Bayer, R. Černý, Effect of high temperatures on the properties of alkali activated aluminosilicate with electrical porcelain filler. *International Journal of Thermophysics*, 2008, vol. 29, p. 693-705.

doi: 10.1007/s10765-007-0311-y

[37] G. Ma, D. Wang, Z. Liu, S. Bi, Y. Zan, B. Xiao, Z. Ma, Effect of hot pressing temperature on microstructure and tensile properties of SiC/Al-Zn-Mg-Cu Composites. *Acta Metall Sin*, 2019, vol. 55, no 10, p. 1319-1328.

[38] A. Dias, V. D. F. C. Lins, Scale morphologies and compositions of an iron-manganese-aluminum-silicon alloy oxidated at high temperatures. *Corrosion science*, 1998, vol. 40, no 2-3, p. 271-280.
doi: https://doi.org/10.1016/S0010-938X(97)00134-0

[39] R. M. Pinto, V. Gund, R. A. Dias, K. K. Nagaraja, K. B. Vinayakumar, CMOS-Integrated Aluminum Nitride MEMS: A Review. *Journal of Microelectromechanical Systems*, 2022, vol. 31, Issue: 4, p 500 - 523.
doi: 10.1109/JMEMS.2022.3172766

[40] T. M Borhan, H. Janna, Thermal properties of cement mortar containing waste aluminium fine aggregate. *Journal of Kerbala University*, 2016, vol. 12, p. 193-200.

[41] T. M. Loganathan, I.Burhan, S. K. B.Abdullah, M. T. H. Sultan, K.Singh, S. Singh, U. Amran . Physical, Mechanical, Thermal Properties of Bio-phenolic Based Composites. *Phenolic Polymers Based Composite Materials*, 2021, p. 169-190.
doi: https://doi.org/10.1007/978-981-15-8932-4_11

[42] D. P. Hochstein, C. Meyer. Measurement and Prediction of Thermal Conductivity of Cement Paste. *ACI Materials Journal*, 2016, vol. 113, no 3.
doi: https://doi.org/10.14359/51688643.

[43] M. Albitar, P. Visintin, M. S. Mohamed Ali, et al. Assessing behaviour of fresh and hardened geopolymer concrete mixed with class-F fly ash. *KSCE Journal of Civil Engineering*, 2015, vol. 19, p. 1445-1455.
doi: https://doi.org/10.15866/irece.v13i4.21515

Authors' information

[1]Geomaterials Development Laboratory, Civil Engineering Department, Faculty of Technology, M'sila University, M'sila 28000, Algeria.

[2]Geomaterials Development Laboratory, Institute of Urban Techniques and Management, M'sila University, M'sila 28000, Algeria.

Dr. **Mekki Maza**, Associate Professor at M'sila University (Algeria), is Civil Engineering, with specialization and PhD in the building materials and structural steel. Since 2000, he has a member of the Laboratory of Geomatics Development, M'sila University, as leader of innovative concrete team. He has participated in several seminars and national and international scientific conferences. Among them,'' Use of a Full Factorial Design to Study the Relationship between Water Absorption and Porosity of GP and BW Mortar Activated''. Advances in Civil Engineering, 2022. and ''Combined effect of marble waste as powder and aggregate form on the proprieties of the mortar''. In : Annales de Chimie-Science des Matériaux. 2021. Innovative concretes, Stuctural Engineering and Materials Engineering are also his research interests.
E-mail: mekki.maza@univ-msila.dz

Dr. **Nadia Tebbal**, Associate Professor at Institute of Urban Techniques and Management, M'sila (Algeria), is Civil Engineering, with specialization and PhD in the building materials and Soil mechanics. She has participated in several seminars national and international scientific conferences. Her latest articles: ''Effects of glass powder on the characteristics of concrete subjected to high temperatures'', Advances in concrete construction, 2018 . ''Durability of high performance sandcretes (HPS) in aggressive environment'', Advances in concrete construction,2019 ,'' Impact of elevated temperatures on the behavior and microstructure of reactive powder concrete '', Construction and Building Materials,2021 and ''Combined Impact of Replacing Dune Sand with Glass Sand and Metal Fibers on Mortar Properties'', Revue des Composites et des Matériaux Avancés,2022.
E-mail: nadia.tebbal@univ-msila.dz

Pr. **Zine El Abidine Rahmouni** was born in M'sila, Algeria. In 1982 he received the engineering degree in Civil Engineering from the Polytechnic School of Algiers (ENP) and PhD-Engineer at INSA Lyon (France) in 1986,. He has joined the University of M'sila on November 7, 1987. Since 2000, he has been a member of the Laboratory of Geomatics Development, M'sila, as leader of innovative concrete team. He has been participated in several seminars and national and international scientific conferences. Innovative concretes, polymer concretes are also his research interests. We mention, ''On the Combination of Silica Fume and Ceramic Waste for the Sustainable Production of Mortar'', Fluid Dynamics and Materials Processing,2023 and ''Impact of rolled and crushed aggregate with natural pozzolan on the behavior of HPC'', Annales de Chimie-Science des Matériaux ,2022.
E-mail: zineelabidine.rahmouni@univ-msila.dz

International Review of Civil Engineering (IRECE)

Aims and scope

The **International Review of Civil Engineering (IRECE)** is a peer-reviewed journal that publishes original theoretical papers, applied papers, review papers and case studies on all fields of civil engineering.

The scope of the Journal encompasses, but is not restricted to the following areas: *infrastructure engineering; transportation engineering; structural engineering (buildings innovative structures environmentally responsive structures bridges stadiums commercial and public buildings, transmission towers, television and telecommunication masts, cooling towers, plates and shells, suspension structures, smart structures, nuclear reactors, dams, pressure vessels, pipelines, tunnels and so on); earthquake, hazards, structural dynamics, risks and mitigation engineering; architectural engineering; environmental engineering; structure-fluid-soil interaction; wind engineering; fire engineering; multi-scale analysis; constitutive modeling and experimental testing; construction materials; composite materials in engineering structures (use, theoretical analysis and fabrication techniques); novel computational modeling techniques; engineering economics..*
The Editorial policy is to maintain a reasonable balance between papers regarding different research areas so that the Journal will be useful to all interested scientific groups.
The Journal also publishes short communications and discussions, book reviews, and a diary on international events related to any aspect of civil engineering.

Instructions for submitting a paper

Contributions may consist of invited tutorials or critical reviews; original scientific research papers (regular paper); letters to the Editor and research notes which should also be original presenting proposals for a new research, reporting on research in progress or discussing the latest scientific results in advanced fields.
All papers will be subjected to a fast editorial process.
Any paper will be published within two months from the submitted date, if it has been accepted.

Papers must be correctly formatted, in order to be published.
Formatting instructions can be found in the last pages of the Review.
An ***Author guidelines*** template file can be found at the following web address:

www.praiseworthyprize.org/jsm/?journal=irece

Manuscripts should be sent via e-mail as attachment in .doc and .pdf formats to:

editorialstaff@praiseworthyprize.com

The regular paper page length limit is defined at **15** formatted Review pages, including illustrations, references and author(s) biographies.
Pages 16 and above are charged 10 euros per page and payment is a prerequisite for publication.

Abstracting and Indexing Information:

Academic Search Complete - EBSCO Information Services
Cambridge Scientific Abstracts - CSA/CIG
Elsevier Bibliographic Database SCOPUS
Index Copernicus - IC Journal Master List 2021: ICV 116.39

Autorizzazione del Tribunale di Napoli n. 22 del 26/02/2010

PWP

Praise Worthy Prize

2036-9913(202309)14:5;1-7