

Conference Paper

Effect of Curing Temperature in the Alkali-Activated Brick Waste and Glass Powder mortar and Their Influence of Mechanical resistances

Zine El Abidine Rahmouni, Nadia Tebbal, and Imen Yamina Omri

Geomaterials Development Laboratory, University of M'sila, M'sila (28000), Algeria

Abstract

In this study, compressive strength values were measured at different curing times (7, 14 and 28 days). The alkali-activation of the brick and glass powder body with potassium water glass having the silicate modulus of 3. Compressive strengths, flexural strength and specific fracture energy of the specimens stored at 40° C and 60° C are evaluated at 28-days. The study demonstrates that the storage temperature of specimens and the content of the alkaline solution have a significant influence on all mechanical properties of the studied materials.

Keywords: brick waste, glass powder, curing temperature, alkali-activated.

Corresponding Author:

Zine El Abidine Rahmouni
zineelabidine.rahmouni@univ-
msila.dz

Received: 20 March 2020

Accepted: 30 April 2020

Published: 13 April 2020

Publishing services provided by
Knowledge E

© Zine El Abidine Rahmouni et al. This article is distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use and redistribution provided that the original author and source are credited.

Selection and Peer-review under the responsibility of the RICON19 - REMINE International Conference Conference Committee.

1. Introduction

The cement industry is one of the major contributors to the emission of greenhouse gasses like carbon dioxide (accounting for around 1.35 billion tons annually). In addition, cement is among the most energy-intensive construction materials [1]. An increasing awareness about ecological issues has encouraged industries to develop building products that will be environmentally friendly and results in structure development [2]. In addition to the reduction in cost and energy saving, the use of SCM in cement for the manufacture of mortar and concrete offers technical advantages [3]. Other possibilities of the production of greener binders or concretes with good performance are provided by alkali activated materials (AAM), where some aluminosilicate precursor is activated by the caustic alkalis or alkaline salts [4, 5].

Recycling the wastes for making useful construction materials is also a key issue towards sustainable development. In this regard, geopolymer played a significant role as an unconventional binding agent for the production of concretes [6]. Geopolymers are inorganic aluminosilicate polymers that are produced via the alkali activation of aluminosilicate ($\text{SiO}_2\text{-Al}_2\text{O}_3$) through a process's called geopolymerisation. Geopolymerization reaction produces a complex three dimensional polymer network, wherein the end

OPEN ACCESS

product (geopolymer) depends largely on the types and proportions of source materials, curing regime and alkaline activators [7].

Amin et al. (2017) showed that utilizing fine dust waste in production of bricks considerably reduced the production cost and enhanced their compressive strength [8]. In another study, Usha et al. (2016) investigated the effect of alkaline solution properties and curing condition on properties of geopolymer mortars based on terracotta roof tile waste. It has been shown that an alkali activator solution-to-binder ratio of 0.8 and a curing temperature of 65° C for 24 h yielded the optimum mix [9].

The effect of the curing temperature was studied by Schi (2005). The mortar compressive strength testing results demonstrated that pozzolanic activity of glass powders is more greatly affected by curing temperature than that of FA [10]. However, Redden and Neithalath (2014) found that high temperature curing conditions did not promote the compressive strength of mortars containing glass powder alone at a relatively low alkali concentration. On the other hand, at a relatively high alkali concentration, the compressive strength of mortars containing FA increased as the curing temperature elevated. The authors assumed that loss of water by heating boosts the polymerization reaction and the combined effect of temperature and water guaranteed the further alkali diffusion, and higher alkalinity that facilitates in the formation of hydration products [11].

Alkali activated materials are formed by alkaline activation of suitable aluminosilicate precursors (e.g metakaolin, blast furnace slag, fly ash). Ceramic and red clay brick wastes are considered to be efficacious aluminosilicate materials, which can be used as alternative to metakaolin and fly ash [12]. Bricks waste is usually rich in glass and burned clays, consisting in dehydrated aluminosilicates not only in crystalline phase but also in amorphous state which is important for alkaline reaction. In recent years, large volumes of brick dust have been produced with the development of building elements for the construction of low- energy houses. The elevated temperature promotes the alkali reaction; the temperature of 60 to 90° C is mostly used, although even at ambient temperature an aluminosilicate gel is formed by brick powder activation [13].

As mentioned in the paragraph above, the literature on combined effect of brick waste and glass powder based geopolymer mortars and their influence of mechanical resistances is limited and there is a need for technical data on the effect of curing condition on the behavior of such mortars.

This study was aimed the effect of curing temperature in BW and GP-based geopolymer mortars. For this purpose, geopolymer mortars with an alkaline solution-to-binder ratio were manufactured. In this regard, the compressive and flexural strength of geopolymers were determined at different curing ages.

2. Materials and Methods

2.1. Materials

Glass Powder (GP): The glass powder obtained by milling mixed recycled bottle glass is provided by a sorting center. The Specific Gravity and Blaine fineness of GP were 2.61 and 1960 cm²/g respectively.

Brick Waste (BW): The brick waste used was from a local manufacturing unit which was crushed in a laboratory mill. Its density and Blaine fineness are 2.55 and 3036 cm²/g. The particle size which done by laser granulometer (Scattering LA-960) of glass powder and brick waste are shown in Figures 1 and 2.

Sand: The standardized sand was also used in this study, conforming to the requirements of EN 196-1 [14].

The alkaline activator solution: The alkaline activator chosen were sodium silicate (Na₂SiO₃) and sodium hydroxide (NaOH). The NaOH was in pellet form with 100.5% purity and 10M solution was fixed. NaOH solution was prepared by dissolving the pellets in one liter of distilled water in a volumetric flask and stirred it. Analytical grade sodium hydroxide in flake form (NaOH with 100.5% purity) and sodium silicate solutions (Na₂O = 10.6 %, SiO₂ = 26.5%, water = 62.9% by mass and SiO₂/Na₂O weight ratio of 3 and a specific gravity of 1.39 at 20 °C), were used as the alkaline activators. The properties of the materials used are shown in table 1.

TABLE 1: Chemical composition of Glass Powder and Brick Waste

Compositions (%)	Glass Powder (%)	Brick Waste (%)
SiO ₂	71.96	62.54
CaO	9.26	8.78
Al ₂ O ₃	1.9	14.31
Fe ₂ O ₃	0.23	5.98
MgO	2.75	2.62
SO ₃	0.08	0.46
MnO	-	-
Na ₂ O	12.25	0.77
K ₂ O	0.28	2.01
Cl ⁻	0.007	0.026
PAF	1.29	2.5

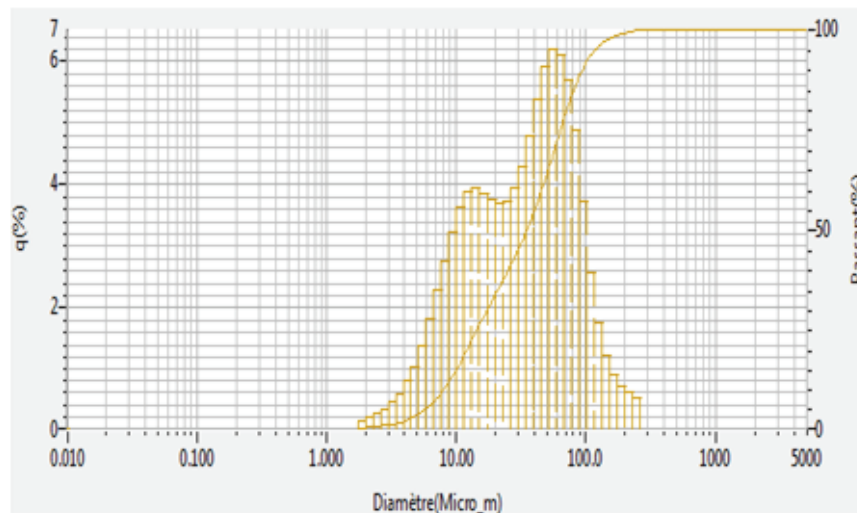


Figure 1: Particle size distributions of glass powder

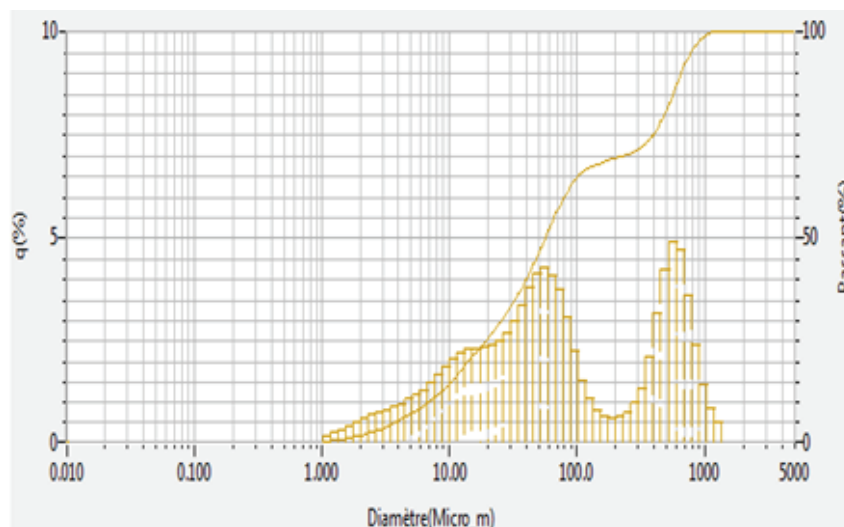


Figure 2: Particle size distributions of brick waste

2.2. Preparation of mortar samples

To develop the alkali-activated binders, glass powder and brick waste materials were mixed with an alkaline solution. The activating solution was prepared by dissolving sodium hydroxide pellets with water and a sodium silicate solution. Glass powder and brick waste were used at proportions of GP: BW-waste of 0:100, 90:10, and 100:00 by weight. Therefore, these mortars were designed as MGP, MWB and M GP90 WB10.

Geopolymer mortar mixes were prepared after replacing cement totally by the same amount of glass powder and activating it by alkaline solutions of sodium hydroxide and sodium silicate. This process has repeated itself for mixtures with 100 BW and for mixture 90% GP+10% BW.

Geopolymer mortars were prepared using 1: 3 proportions of GP and standard sand. For the mixing procedure, NaOH solution, base water and binder of filler were first mixed for 5min in a pan mixer. Sand was then added and mixed for 5min. Finally, sodium silicate solution were included and mixed for another 5 min. This mixing procedure was test and found to produce high strength geopolymer. Subsequent to mixing, were molded in 2.5 cm x 2.5 cm x10 cm prismatic. A plastic film was used to cover the sample molds to avoid water loss due to the curing process. After 24 hours at laboratory temperature, the specimens were cured in an oven for 24 hours at 40 and 60° C. After curing at an elevated temperature, the mortars were put in laboratory to cool down and demoulded the next day and kept in 25° C room until testing age. The specimens were tested at the age of 7days and 28days. Thereafter, the specimens were further cured for 1, 7 and 28 days at room temperature until the mechanical analysis.

Strength, porosity and absorption test: The mortar compressive strengths test were determined using prismatic specimens of square section 2.5 cm x 2.5 cm and length 10 cm in accordance with EN 196-1[14].. Microstructure of the fractured sample was characterized by using optical microscope.

3. Results and Discussions

3.1. Effect of curing temperature on compressive strength

Figures 3 and 4 show the effect of curing temperature of MBW and MGP on the 7, 14 and 28 days mechanical strength of different geopolymer mixes. At a 40° C, the compressive strength of mix MBW was 2 MPa, 4 MPa and 5 MPa, respectively. The mix MGP reached a value of 13.54 MPa, 15.04 MPa and 33.71 MPa (4 to 6 times greater than M BW).

From 60° C, histograms of the sample MGP exhibit a normal and accelerated evolution of strength gain; that is, a rapid strength gain in the seven first days of curing, and from this moment, M GP have a slow or gradually strength-gain which it stabilizes at 28 days of age.

On the other hand, the compressive strength of mortar MBW increases slowly when compared with that of MGP. It can be concluded that the mix MGP exhibited the higher mixes, and further, the strength increase as the curing temperature increases from 40° C to 60° C. This trend is even more obvious at 28 days when all the mortar mixes with glass powder are superior to the MBW regarding compressive strength. This increase in compressive strength for mortar with glass powder is attributed to the pozzolanic reaction and a higher amount of calcium oxide, silica oxide and alumina, consequently

enhancing the compressive strength of MGP mix. The availability of the high amount of calcium and alumina in the mix leads to the formation of additional calcium silicate hydrate gel with high amounts of tetra-coordinated 'Al' in its structure as well as Na ions in the interlayer spaces; hence, higher compressive strength is obtained [15]. By comparing the percentage of compressive strength enhancement of the MBW series with that of the MGP series, the conclusion that high temperature is essential for the developments of early strength could also be obtained. It is because the chemical properties of low calcium BW are not very lively and the geopolymerization could not progress at a normal speed when cured at 40° C. It can be concluded; the temperature 60° C can accelerate the speed of geopolymerization and shorten the setting and hardening time. Therefore, the specimens cured at temperature 60° C produced high ultimate strength and early strength.

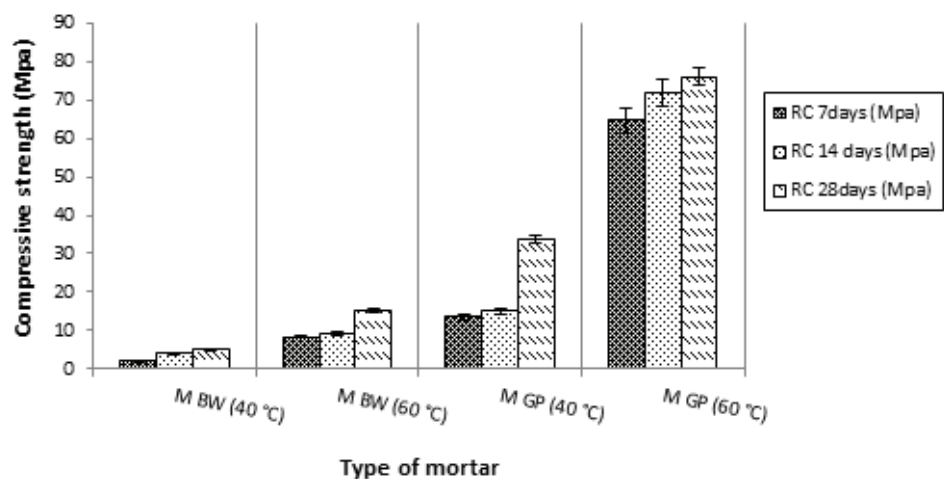


Figure 3: Compressive strengths for MBW and MGP depending on the activation temperature

3.2. Effect of curing temperature on flexural strength

Figure 4 shows the flexural strength of mortars at different curing ages. Specimens cured at a temperature of 60° C demonstrated the highest flexural strength. For example,, the 28-day flexural strength of MGP increased by 32.5%, when the curing temperature increased from 40° C to 60° C. For duration of 28 days, the strengths of MBW were 9 and 11.29 MPa.

As discussed earlier, the heat curing of geocement mortars increases the flexural strength due to accelerated polymerization reactions. However, the optimum curing temperature depends on the morphology and chemical composition of the precursor. According to the research of Hardjito et al. 2008, the liquid content starts to decline

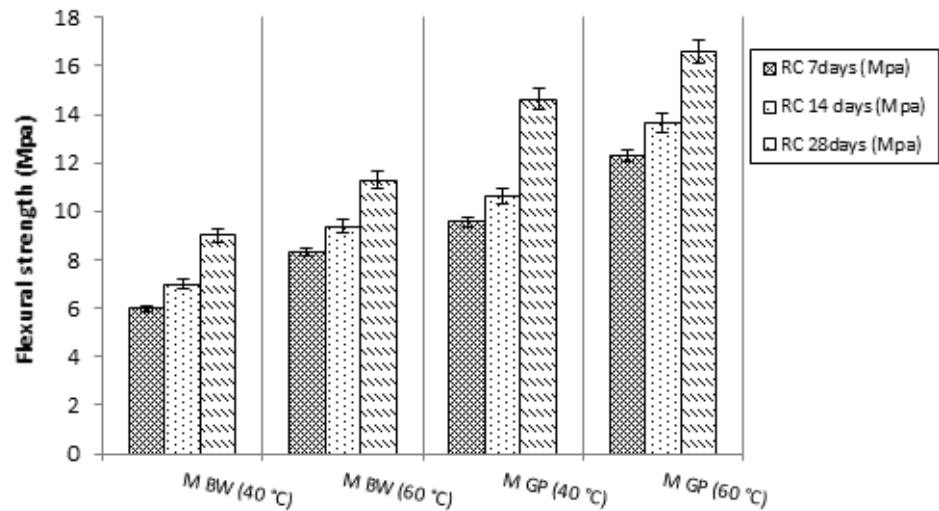


Figure 4: Flexural strengths for MBW and MGP depending on the activation temperature

due to evaporation of the water, which negatively affects the geopolymerization process at high curing temperatures [16]. Chindaprasirt et al. (2007) confirmed that moisture is required to produce geopolymer with good strength [17].

3.3. Effect of curing temperature of geopolymer binders with BW and GP activated

Strength of geopolymer mortar cured at 40° C and 60° C at the age of 7, 14 and 28 days as presented in figures 5 and 6. The mechanical strength of all samples incorporating BW and GP was quite different from that MBW and MGP.

All mixes follow a similar trend where brick waste and glass powder included in mortars resulted in increased mechanical strength.

An increase in the compressive strength with age 7 to 28 days was noted in all the mortar samples, irrespective of the curing or mixing methods used. However, for the blended mortar BW and GP samples, the compressive strength development is greater at 7, 14 and 28 days in 60° C cured samples than for the 40° C cured ones. The 7 day compressive strength for the MGP samples has greater early stage development compared to the equivalent 7 day of MBW cured samples (Figure 5). This result can be attributed to the brick waste based geopolymer needs sufficient time for the geopolymerization process to happen, and therefore, in order to increase the dissolution of reactive species sufficient amount of heat influx is needed for strength gain.

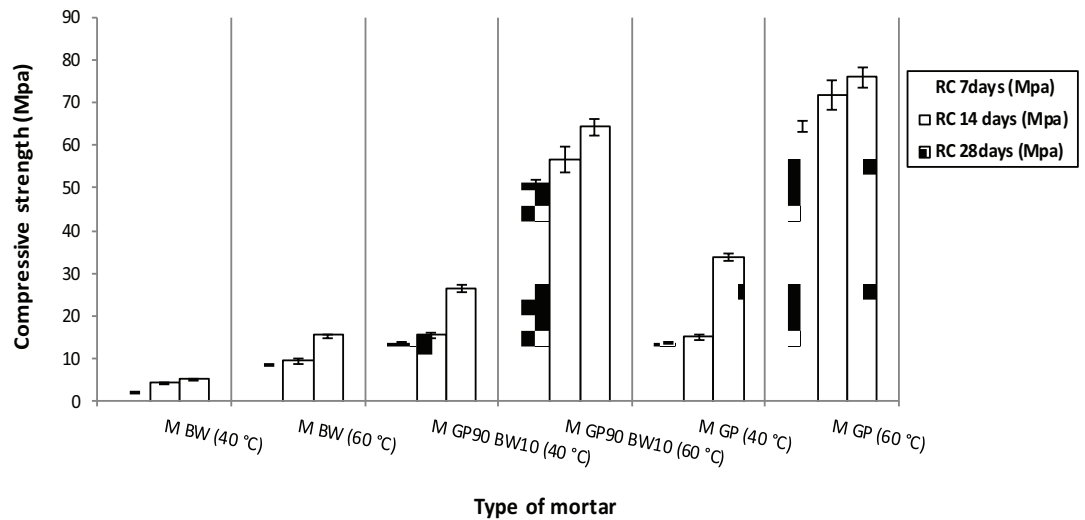


Figure 5: Compressive strength of mortars at different curing ages

The graphical demonstration shows the successive increments in compressive strength with prolong curing. The incorporation of supplementary glass powder in brick waste based geopolymer up to 90 % of GP gets better chemistry in geopolymerization. Many research confirmed this higher compressive strength can be attributed to the filling effect, due to the dissolute ion of brick, glass and the format ion of hydration products (CSH) as well as the Geopolymer gel filling the empty cavities which form compacted Geopolymer structures [18].

The test results of the flexural strength at different ages and different mortars are shown in Figure 6.

It is noted that after 7, 14 and 28 days, the flexural strength of M GP90BW10 increases with increasing temperature of curing. This increase compared to the M BW is 36.56 %, 41.47 % and 72 % for curing temperature 40° C, respectively. After 28 days of curing, the M GP in the same temperature of curing, the increase in flexural strength was 7.45 %. At higher temperature (60° C) the flexural strength of mixes with brick powders is slightly improved.

The mixture M GP90BW10 has been an exceptional increase more than M BW. An increase of 74% is observed for the mix with 10% brick fines and 90% glass powder (MGP90BW10) whereas a comparable flexural strength is obtained for the mix with 100% glass powder (M GP). The slowly in flexural strength at early age is probably due to a decrease in temperature of binder activity caused by the dilution effect.

At the 60° C, the improvement of the flexural strength for mixes incorporating brick powders and glass powder could be explained by the improvement of hydration. The

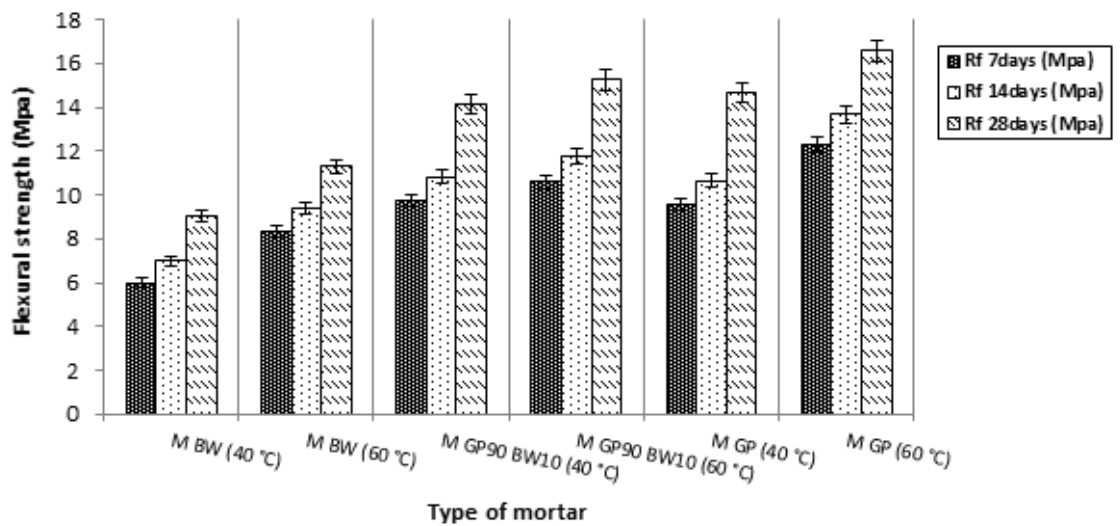


Figure 6: Flexural strength of mortars at different curing ages

reaction of the limestone fillers present in the glass powder with the aluminates brought by the brick powders to form mono-carbo-aluminates also contributes to the formation of more hydrates and hence contributes to the improvement of the flexural strength [19].

3.4. Crushing the Mortar specimens aspect after curing temperature

Figures 7 and 8 present the appearance of specimens after heating. Clear differences can be noticed of the materials compared.

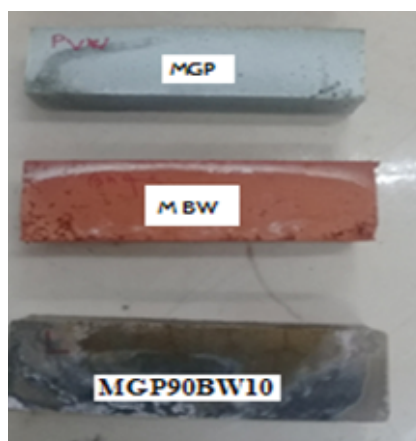


Figure 7: Appearance of specimens after curing temperature test

Based on the visual inspection of specimens (Figure 8), the geopolymer mortar exhibited significantly better resistance. On the photographs above, changes in the color of mortars based on geopolymer and mortar binders as a result of heating are

4. Conclusions

By designing three geopolymer concrete mixtures, this paper studied the effect of curing temperature in the alkali-activated brick waste and glass powder mortar and their influence of mechanical resistances. The following conclusions are drawn:

1. For the polymerization the heat is required to the geopolymer mortar;
2. The combination of brick waste with glass powder affects the geopolymer mortar performance in the short term;
3. The mechanical strength increases with the incorporation of brick powder at early age;
4. At 60° C, such strengths are improved, especially for the mix with 10% brick fines and 90% glass waste (M GP90BW10) compared to mortars 100% brick waste (M BW).
5. Specimen M BW shows very small percentage of increment in compressive strength for longer curing duration for a curing temperature up to 60° C, but every case this increment is not greater than 10% even. Furthermore a curing duration of 24 hours for a curing temperature greater than 40° C gives poor result in connection in compressive strength.

Acknowledgments

The authors thank the Geomaterials Development Laboratory of M'sila University and Directorate of Scientific Research and Technological Development (DGRSDT, MESRS, Algeria) for the assistance and support to complete this paper.

References

- [1] Hardjito, D., Wallah, S. E., Sumjouw, D. M. J. *et al.* (2003). Keynote Paper: *International Conference on Recent Trends in Concrete Technology and Structures, INCONTEST*, 10-11 September, Coimbatore, India.
- [2] Singh, P., Sharma, S. K., Gupta, M. H. *et al.* (2016). Development of Geopolymer Bricks using Foundry Sand. *International Research Journal of Engineering and Technology (IRJET)*, vol. 3, issue 8, pp. 2045-2050.

- [3] Si-Ahmed, M., Kenai, S. and Ghorbel, E. (2018). Performance of cement mortar with waste ground clay brick. *MRS Advances*, vol. 3, issue 34-35, pp. 2041-2050.
- [4] Shi, C., Krivenko, P.V., and Roy, D. (2006). *Alkali-activated cements and concretes*. (London: Taylor & Francis).
- [5] Davidovits, J. (1999). Chemistry of Geopolymeric Systems, Terminology. In Proceedings of the 99 *International Conference*. eds. Joseph Davidovits, R. Davidovits and C. James, (France)
- [6] Huseien, G., Ismail, M., Tahir, M., et al. (2018). Performance of sustainable alkali activated mortars containing solid waste ceramic powder. *Chemical Engineering Transactions*, vol. 63, pp. 673-678.
- [7] Duxson, P., Provis, J. L., Lukey, G. C., et al. (2007). The role of inorganic polymer technology in the development of 'green concrete'. *Cement and Concrete Research*, vol. 37, issue 12, pp. 1590-1597.
- [8] Amin, S. K., El-Sherbiny, S. A., El-Magd, A. A., et al. (2017). Fabrication of geopolymer bricks using ceramic dust waste. *Construction and Building Materials*, vol. 157, pp. 610-620.
- [9] Usha, S., Nair, D. G., and Vishnudas, S. (2016). Feasibility study of geopolymer binder from terracotta roof tile waste. *Procedia Technology*, vol. 25, pp. 186-193.
- [10] Shi, C., Wu, Y., Riefler, C., et al. (2005). Characteristics and pozzolanic reactivity of glass powders. *Cement and Concrete Research*, vol. 35, issue 5, pp. 987-993.
- [11] Redden, R., and Neithalath, N. (2014). Microstructure, strength, and moisture stability of alkali activated glass powder-based binders. *Cement and Concrete Composites*, vol. 45, pp. 46-56.
- [12] El-Fadaly, E., Mostafa, M. R., Saraya, M. E. I., et al. (2014). Eco-friendly cement from ceramic waste geopolymerization. *Natural and Social Sciences*, vol. 2, issue 5, pp. 195-210.
- [13] Bignozzi, M. C., Fusco, O., Fregni, A., et al. (2014). Ceramic waste as new precursors for geopolymerization. *Advances in Science and Technology*, vol. 92, pp. 26-31.
- [14] EN, N. (2006). 196-1, *Méthodes d'essais des ciments-Partie 1: détermination des résistances mécaniques*. French Standard.
- [15] Sethi, H., Bansal, P. P., and Sharma, R. (2019). Effect of addition of GGBS and glass powder on the properties of geopolymer concrete. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, vol. 43, issue 4, pp. 607-617.
- [16] Hardjito, D., Cheak, C. C., and Ing, C. H. L. (2008). Strength and setting times of low calcium fly ash-based geopolymer mortar. *Modern applied science*, vol. 2, issue 4, pp. 3-11.

- [17] Chindapasirt, P., Chareerat, T., and Sirivivatnanon, V. (2007). Workability and strength of coarse high calcium fly ash geopolymer. *Cement and concrete composites*, vol. 29, issue 3, pp. 224-229.
- [18] Sitarz, M., Hager, I., and Kochanek, J. (2018). Effect of High temperature on mechanical properties of geopolymer mortar. *MATEC Web of Conferences*, vol. 163, p. 6004.
- [19] Bizzozero, J., and Scrivener, K. L. (2015). Limestone reaction in calcium aluminate cement–calcium sulfate systems. *Cement and Concrete Research*, vol. 76, pp. 159-169.