The 57th International October Conference on Mining and Metallurgy
05 - 07 October 2026, Bor Lake, Serbia
https://ioc.irmbor.co.rs

DOI: 10.5937/IOC26193T Original Scientific Paper- Materials Science

# INFLUENCE OF CURING TEMPERATURE ON THE PROPERTIES OF FLY ASH-BASED GEOPOLYMERS DOPED WITH A WASTE PLASTIC

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## Abstract

*This study investigates the influence of curing temperature on the properties of fly ash-based geopolymer composites containing waste high-density polyethylene (HDPE) and polypropylene (PP). Geopolymer specimens were prepared by replacing 10 wt.% of fly ash with plastic waste particles and cured at temperatures ranging from 20°C to 65°C. The mechanical properties, including compressive and flexural strength were evaluated. The results showed that increasing curing temperature significantly enhanced the mechanical performance of both HDPE- and PP-doped fly ash-based geopolymer composites. The highest compressive and flexural strengths were obtained for both, HDPE and PP composites, at 65°C.*

***Keywords**: Fly ash, HDPE, PP, geopolymer*

## 1. INTRODUCTION

In modern civil engineering and materials science, increasing attention is being devoted to the development of environmentally friendly and sustainable materials that can be used as an alternative to conventional cement-based systems. The production of Portland cement is associated with significant carbon dioxide emissions [1] and high energy consumption, which has encouraged intensive research into materials with lower environmental impact. One of the most promising solutions is production of geopolymers, inorganic aluminosilicate materials obtained through the alkaline activation of industrial by-products rich in silicon and aluminum, such as fly ash. It is reported that geopolymer binders can deliver an 80%-or-greater reduction in $CO_2$ emissions compared to Portland cement [2].

Fly ash-based geopolymers are characterized by good compressive strength, high chemical and thermal stability [3]. The geopolymerization process of fly ash (and

aluminosilicate materials in general) involves the chemical reaction of aluminosilicate oxides with a highly alkaline activator, resulting in the formation of a new material with an amorphous or semi-amorphous structure, a geopolymer known as sodium aluminosilicate hydrate (N-A-S-H) gel [4].

Currently, extensive research is carried out in the field of synthesis of geopolymers materials which could be used as a thermal insulation material [5,6]. In this sense, the subject of this study was to investigate the synthesis of fly ash-based geopolymer composites doped with a waste plastic, high-density polyethylene (HDPE) and polypropylene (PP), with the aim of analyzing their mechanical, physical, and microstructural characteristics. Special emphasis is placed on the influence of temperature and time of curing on the mechanical properties of geopolymers doped with a HDPE and PP.

## 2. EXPERIMENTAL

Fly ash was suplied form coal fired power station in Pljevlja and plastic waste (PP and HDPE) from the MONTWAY Podgorica. The chemical composition of fly ash is given in Table 1. Fly ash-based geopolymers containing plastic waste PP and HDPE were prepared by adding PP and HDPE to the starting mixture by fly ash replacement with a 10% to the fly ash solid content. First, fly ash was mixed with alkali activator at solid to liquid (S/L) ratios of 1.4. And then, plastic waste was added. Alkali activator was prepared by mixing of 7M NaOH solution and $Na_2SiO_3$ solution (commercial water glass) in a mass ratio of 1. Prepared geopolymers were casted in a plastic mold, sealed with a lead and cured in the oven at the temperature of 45°C, 55°C and 65°C for the period of 24 h. Curing was also carried out at the room temperature. After 7 days, the samples were removed from mold, rest the room conditions additional two weeks and tested for compressive and flexural strength.

**Table 1.** *Chemical composition of fly ash*

| Component | Content, (wt.%) |
|---|---|
| $SiO_2$ | 41.64 |
| $Al_2O_3$ | 19.30 |
| $Fe_2O_3$ | 5.70 |
| CaO | 16.9 |
| MgO | 1.84 |
| $K_2O$ | 2.63 |
| $Na_2O$ | 0.39 |
| $SO_3$ | 0.02 |
| Cl | 0.02 |
| $P_2O_5$ | 0.25 |
| MnO | 0.06 |
| $Cr_2O_3$ | 0.03 |
| $TiO_2$ | 0.54 |
| Loss of ignition | 4.26 |

## 3. RESULTS AND DISCUSSION

Cross-sections of specimens after flexural strength testing where particles of HDPE and PP bounded in the reaction product of fly ash geopolymerization are clearly visible are given in the Figure 1(b, d). The cross-section surfaces reveal the structural characteristics of the geopolymer composites and the interaction between the geopolymer matrix and incorporated plastic particles. HDPE and PP particles are clearly embedded within the geopolymer reaction products formed during fly ash geopolymerization. The plastic particles appear to be well dispersed throughout the matrix and remain bonded to the surrounding geopolymer gel, indicating good interfacial adhesion.

Figure 2 presents the effect of temperature on the compressive strength and flexural strength of HDPE- and PP-based specimens. The results demonstrate that temperature plays a significant role in determining the mechanical performance of both thermoplastic materials.

As shown in Figure 2(a), the compressive strength of both HDPE and PP specimens increased markedly with increasing temperature. For HDPE, compressive strength increased from approximately 3 MPa at 20°C to about 30 MPa at 65°C, while PP exhibited an increase from approximately 3 MPa to 24 MPa over the same temperature range. This trend indicates that elevated temperatures promote improved particle bonding and structural consolidation within the material matrix. The enhancement was more pronounced for fly ash - HDPE based geopolymer composites. The highest compressive strengths were achieved at 65°C for both materials, suggesting that this temperature provides favorable conditions for the development of compressive resistance.

Figure 2(b) shows the variation in flexural strength with temperature. Unlike compressive strength, the increase in flexural strength was less pronounced. The both, HDPE and PP doped fly ash-based composites exhibited a rise in flexural strength from approximately 0.3 MPa and 0.53 MPa at 20°C to a maximum of about 1.9 MPa and 2.1 MPa at 65°C, respectively for HDPE and PP doped fly ash-based geopolymer composites. In contrast to the change of compressive strength with a rise of temperature, he enhancement of flexural strength was more pronounced for fly ash- PP based geopolymer composites.

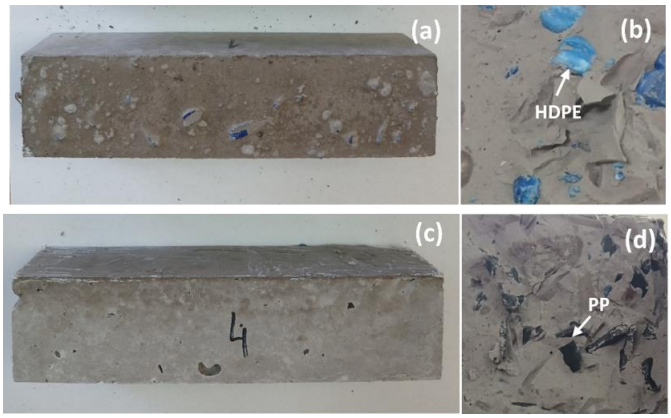



**Figure 1.** *The samples of fly ash-based geopolymers doped with 10% of HDPE (a) and its cross-section (b) and fly ash-based geopolymer doped with 10% PP (c) and its cross-sections (d)*

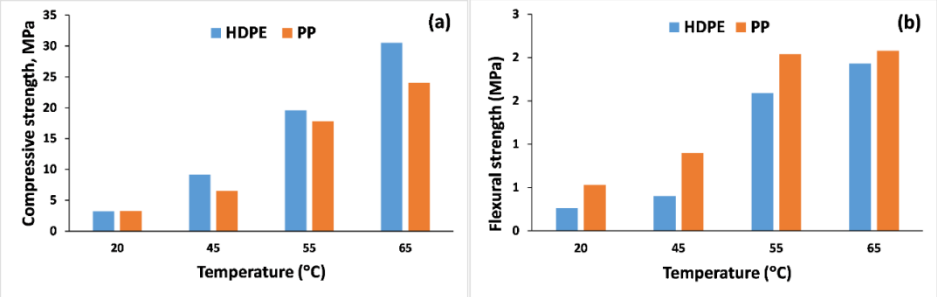



**Figure 2.** *Influence of temperature of curing on the: compressive strength (a) and flexural strength (b)*

## 4. CONCLUSION

Fly ash-based geopolymer composites containing 10 wt.% waste HDPE and PP particles were successfully synthesized at different curing temperatures. The obtained results demonstrated that curing temperature plays a crucial role in the development of mechanical properties of geopolymer composites.

Thermal treatment at approximately 65°C appears to provide the most favorable conditions for maximizing both, compressive and flexural strength. HDPE-modified geopolymers exhibited higher compressive strength than PP-containing composites throughout the investigated temperature range, reaching approximately 30 MPa at 65°C. In contrast, PP-modified fly ash-based geopolymer composites showed the higher flexural strength compared to those prepared with HDPE.

## ACKNOWLEDGEMENTS

*The authors are grateful to the Innovation Fund of Montenegro for financial support according to the contract with registration No. CGI-004-24.*

## REFERENCES

[1] M. Schneider, M. Romer, M. Tschudin, H. Bolio., Cem. Concr. Res., 41 (7) (2011) 642-650.
[2] C. Horan, M. Genedy, M. Juenger, E. van Oort., Energies, 15 (23) (2022) 8819.
[3] F. Fan, Z. Liu, G. Xu, H. Peng, C.S. Cai., Constr. Build. Mater., 160 (2018) 66-81.
[4] J. Davidovits, J. Journal of Thermal Analysis, 37 (8) (1991) 1633–1656.
[5] P.S. Soe, W. Sornlar, A. Wannagon, D. Chaysuwan., J. Mater. Cycles Waste Manag., 25 (5) (2023) 2964-2975.
[6] P.R. Rao, M. Momayez, K.A. Runge, K. Muralidharan., Mining Metall. Explor., 37