Predictive analysis of brick powder-enhanced self-compacting mortar using artificial neural networks

Zine El Abidine Laidani[a], *Mohamed* Sahraoui[b], *Younes* Ouldkhaoua[c], *Benchaa* Benabed[d], *Mohamed El Ghazali* Belgacem[e]

[a] Blida1 University, Civil Engineering Department, Blida, People's Democratic Republic of Algeria,
e-mail: laidani_z@univ-blida.dz, **corresponding author**,
ORCID iD: https://orcid.org/0000-0002-8502-9819

[b] Blida1 University, Institute of Architecture and Urbanism, Blida, People's Democratic Republic of Algeria,
e-mail: sahraoui_mohamed@univ-blida.dz,
ORCID iD: https://orcid.org/ 0000-0003-4670-9755

[c] University of Science and Technology – Houari Boumediene, Faculty of Civil Engineering, Building in Environment Laboratory, Algiers, People's Democratic Republic of Algeria,
e-mail: younes.ouldkhaoua@usthb.edu.dz,
ORCID iD: https://orcid.org/ 0009-0001-8334-812X

[d] University of Amar Telidji, Department of Civil Engineering, Civil Engineering Research Laboratory, Laghouat, People's Democratic Republic of Algeria,
e-mail: b_benchaa@yahoo.fr,
ORCID iD: https://orcid.org/ 0000-0002-3352-1588

[e] University of Science and Technology – Houari Boumediene, Faculty of Civil Engineering, Building in Environment Laboratory, Algiers, People's Democratic Republic of Algeria,
e-mail: ghazali2017@gmail.com,
ORCID iD: https://orcid.org/ 0000-0001-8515-8568

doi https://doi.org/10.5937/vojtehg73-55812

FIELD: civil engineering, materials, deep learning
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Self-compacting mortars possess very good flowability which enables them to consolidate only through the force of their self-weight, not demanding any mechanical vibration. This type of mortars has a significant value in complicated construction and repair works. In this paper, research will be conducted on using brick powder as replacement for cement in SCM with a detailed study of effects on workability, compressive strength, and all other performance.

Methods: The proposed research models the relationships of different parameters, brick powder content and fineness, with the resultant properties of mortar using artificial neural networks (ANN) models.

Results : The results showed that the addition of brick powder up to 10% of cement as replacement improves mortar workability, giving the slump flow ranging from 306 to 309 mm and the funnel flow time between 4.8 and 5.4 s, while its compressive strength was ranging from 45 to 60 MPa at 28 days. However, at replacement levels higher than 20%, the slump flow was reduced to 285 mm, the time to funnel flow increased to 9 s, and the compressive strength decreased to 35 MPa.

Conclusion: The study illustrates brick powder as a promising recycled material for SCM applications not only to reduce environmental impacts but also to improve performance, although optimization of its replacement levels should be taken carefully to balance workability and strength.

Key words: brick powder, self-compacting mortar, cement, workability, artificial neural networks, slump flow, funnel flow time, compressive strength.

Introduction

Self-compacting mortar (SCM) is a type of mortar that can flow and consolidate under its own weight without any added mechanical vibration. This property adds value to SCM while building applications particularly in complex shapes and dense steel reinforced structures where common mortar struggles to fill voids. SCM's ability to achieve uniform placement enhances product quality and durability while improving efficiency and reducing labor costs. These benefits have contributed to the extensive use of SCM in contemporary constructions, especially in precast elements and rehabilitation activities.

The design and selection of self-compacting mortar (SCM) qualities and compositions in practical applications are dependent on various aspects, including workability, strength requirements, and material availability. Workability, characterized by measures such as slump flow, V-funnel flow time, and viscosity, is essential for achieving enough consolidation without external vibration, rendering SCM especially advantageous in highly reinforced structures and complex formwork geometries (Nepomuceno et al., 2012).

The mixture design of SCM generally follows the established approaches such as the EFNARC (European Federation of National Associations Representing Concrete) guidelines, which recommend, for the optimal ratios of cement, supplementary cementitious materials SCMs, fine aggregates, superplasticizers, and viscosity-modifying agents (Ashish and Verma, 2019) (concrete, 2005). A high-flowability supplementary cementitious material (SCM) designed for narrow-section precast elements might require a higher quantity of superplasticizer and a reduced water-to-binder ratio to sustain fluidity and prevent agglomeration (Ghafari et al., 2016). Conversely, a supplementary cementitious material (SCM) designed for structural restoration applications may integrate pozzolanic substances such as fly ash, silica fume, or brick powder to improve durability and long-term strength.

Given the emergence of global urbanization trends, the construction sector is plagued with challenges of sustainability with a keen need for sustainable alternatives. Cement is, however, the third-highest source of CO_2 emissions globally, accounting for nearly 5% of worldwide emissions (Benhelal et al., 2021). Also, extraction of natural aggregates causes many harmful effects on the environment (Pacheco-Torgal et al., 2012).

The search for sustainable alternatives has led to the exploration of waste materials such as brick powder (BP) made from recycled bricks, which minimizes landfill trash and requirements for new raw materials Silva et al., 2016). Typically, BP contains natural silica (SiO_2), alumina (Al_2O_3), and iron oxides that are essential to the pozzolanic activity which enhances strength and durability, making it an attractive choice for SCM (Mansoor et al., 2024).

The use of brick powder waste as supplementary cementitious materials in SCM has been treated in detail by Bouleghebar et al. (2023). The authors proposed substituting cement by weight with 4, 8, 12, 16, and 20% BP, having three levels of Blaine fineness (F1=3300 cm^2/g, F2=4400 cm^2/g, and F3=6000 cm^2/g). The study reported the improvement of the mechanical properties and reduced porosity of mortars in this format, giving them potential in sustainable construction practices and resources conservation.

The study of Si-Ahmed and Kenai (2020) evaluated the effect of utilizing waste BP as a partial replacement for cement in SCMs. It was reported that replacements levels up to 15% of cement had a limited effect on rheology and positively affected long-term compressive strength. However, beyond that percentage, workability was diminished by the increase in water absorption of BP. A slight increase in water absorption by capillarity was reported in this work; this shows a compromise between strength and permeability. This confirms the possibility of using waste BP in SCMs towards sustainability.

Another study carried out by Boukhelkhal and Benabed (2019) assessed the effect of waste brick powder (WBP) as a filler material in self-compacting repair mortar (SCRM) by partially replacing Ordinary Portland Cement (OPC) at substitution levels of 5, 15, and 25%. They found that the incorporation of 5% WBP improved the flowability and stability of mixtures in a fresh state, while at a level of substitution up to 25%, the replacement caused a significant decrease in slump flow. Moreover, in terms of hardened state, the compressive strength decreased by 10.6% at 15% replacement and by 35.3% at 25% replacement levels, highlighting the potential of WBP to produce a new reduced carbon blended cement, which enables reduced carbon emission while achieving environment-friendly sustainability.

The effect of recycled brick powder (RBP) as a partial cement replacement in SCM was the research topic of Irki et al. (2018), who used varying replacement levels (0, 5, 10, 15 and 20%) and three Blaine fineness values (3900, 4300, and 5200 cm²/g). The results showed that increasing the RBP content led to a decrease in workability, with a 30% reduction observed at more than 20% replacement. However, compressive and splitting tensile strengths improved with higher Blaine fineness and 5% to 10% RBP substitution, attributed to the pozzolanic activity, indicating significant long-term strength gains.

Karatas et al. (2010) analyzed the influence of Elazig region waste brick powder (WBP) on the strength and viscosity properties of SCM. They found that the compressive strength of SCM mixtures made with 5 and 10% WBP exhibited higher compressive strength at early curing ages compared to mixtures without WBP. Beyond this range, the compressive strength of SCM diminished as WBP content increased. Furthermore, the research highlighted that WBP increased cohesion in mortars but decreased its flowability due to the viscous nature of the admixture.

Despite an increasing interest in alternative materials for SCM, there is limited research that examines the use of Artificial Neural Networks (ANNs) to predict the effectiveness of such materials, in the form of BP, on SCM performance. It has been confirmed that ANNs are successful in modeling, solving and understanding complex relationships, particularly in mortar and concrete, as they are heterogeneous materials which makes it difficult to predict their behaviour, using simple analytical methods. However, the use of ANNs to study how BP affects workability, strength and durability of SCM is lacking. Utilizing AAN systems could improve prediction accuracy and optimization according to changed properties of recycled materials as BP, and improving sustainable practices in construction.

The TanH function was chosen for enabling effective gradient flow during backpropagation and convergence stability enhancement (Yan et al., 2022). This activation function is particularly advantageous in modeling construction material properties, as it handles both positive and negative input data, ensuring the model accurately represents the complex interactions in cementitious systems (Sathiparan et al., 2024).

This study's primary goal is to use artificial neural networks (ANNs) to analyze the effects of using BP as an alternative material in SCM. It aims to model the relationship between the amount of BP added and the resulting properties of SCM such as flowability and compressive strength. The study uses neural networks to optimize the mix design of SCM containing BP, ultimately helping to the development of sustainable construction materials and practices. This approach will aid to better understand the performance of BP in SCM while also demonstrating the efficiency of computational tools in cementitious material science.

Methodology

Data collection and preparation

The dataset used in this study was collected to evaluate the influence of BP on the flowability and compressive strength of self-compacting mortar. The key parameters analyzed are:

- Superplasticizer content (%),
- Cement content (Kg/m³),
- Water-to-binder ratio W/B,
- Brick powder (%),
- Sand content (Kg/m³),
- Fineness of brick powder (cm^2/g),
- Dune sand content (Kg/m³), and
- Si/Al/Fe content in BP (%).

The target variables for this study are :

- Slump flow (mm),
- V-funnel flow time (sec), and
- Compressive strength at 28 days (MPa).

The dataset needed to perform this analysis is detailed in the Appendix (Table 1) along with some basic properties of cement and aggregates (Table 2) to enable full documentation and transparency in the study (i.e., the dataset required contains every single detail of all mixtures). It should also be noted that selecting the data was conducted only with mixtures having comparable properties as the same cement types (CEM I) and a superplasticizer of a single type generation were used. This method improves the dataset reliability and the validity of the analysis.

The dataset included some missing values which were addressed through mean imputation. After imputation, the features were scaled using a standard scaler to standardize them to a mean of 0 and a standard deviation of 1. This preprocessing step was essential for the effective operation of the neural network (Aksu et al., 2019).

Model generation

The ANN models used in this study effectively capture the relationships between the key input parameters and the properties of SCM in both its fresh and hardened states. Figure 1 illustrates the ANN structure for predicting the fresh-state properties, namely slump flow (mm) and V-funnel flow time (sec). The inputs to this model include superplasticizer (Sp) content, BP percentage, and BP fineness (cm^2/g), all of which significantly influence workability and flowability. These parameters interact through the ANN's hidden nodes to produce accurate predictions for fresh-state performance.

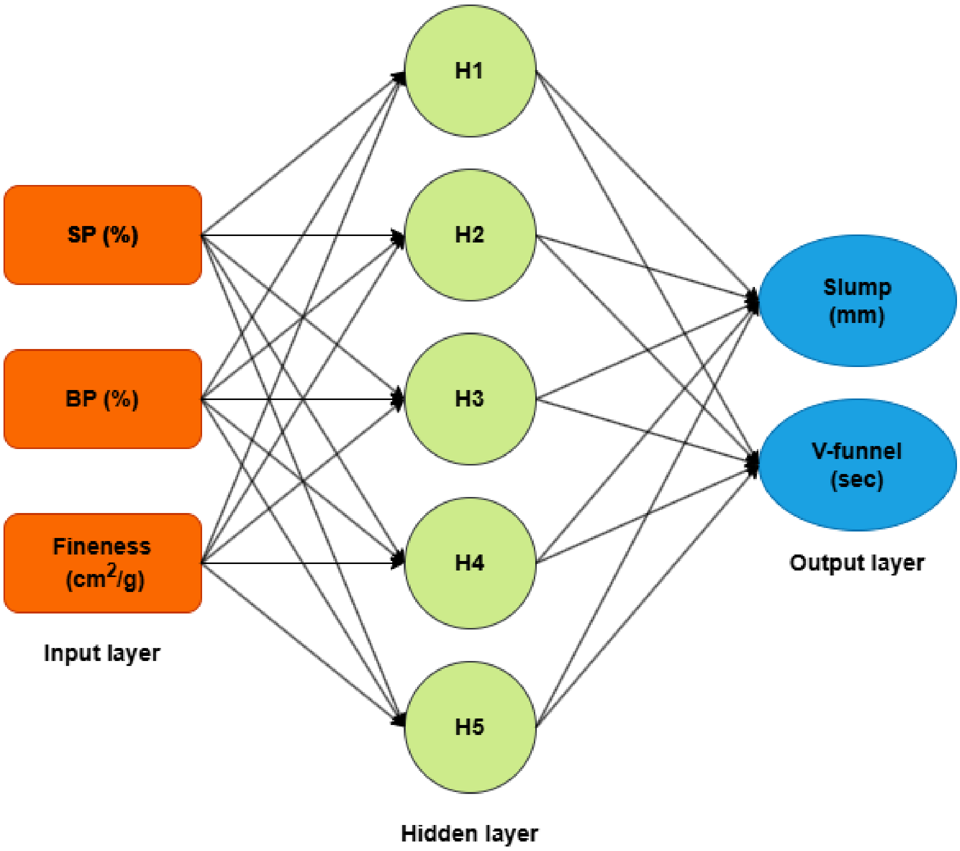

Figure 1 – Schematic diagram of the ANN model for predicting slump flow and V-funnel flow time

On the other hand, the ANN developed for predicting hardened-state properties, specifically compressive strength (MPa), is shown in Figure 2. This model identifies the BP fineness, the Al-Si-Fe composition of brick powder, and the BP percentage as the primary factors affecting strength.

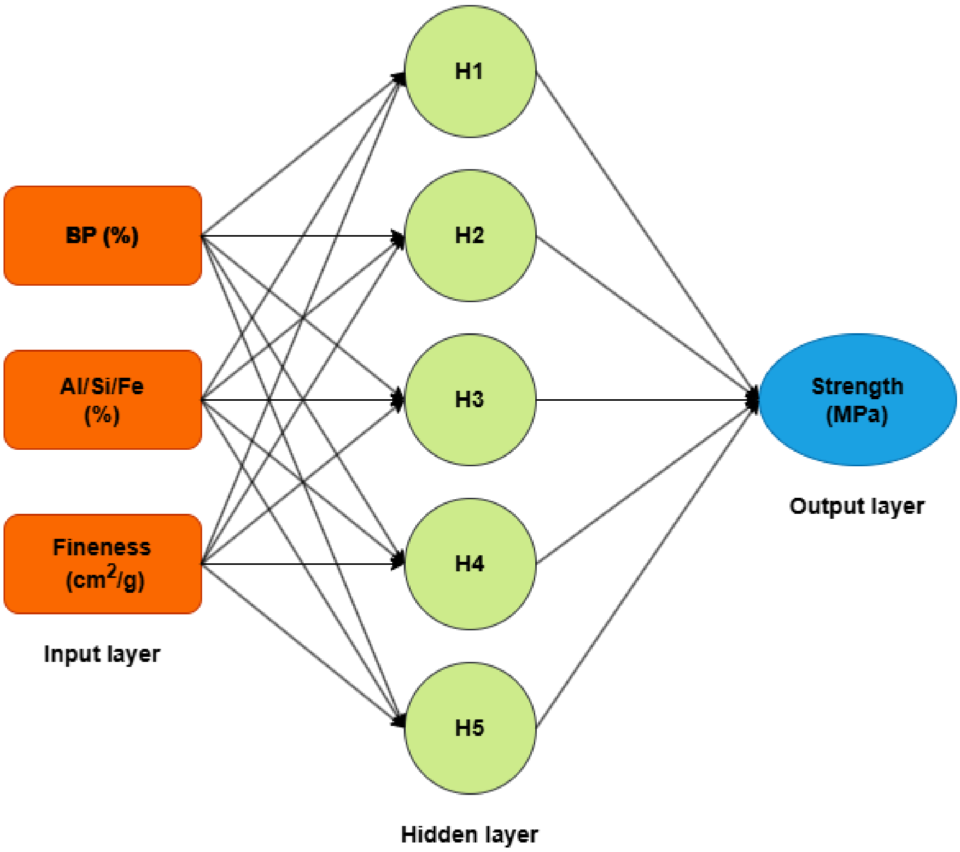

Figure 2 – Schematic diagram of the ANN model for predicting compressive strength

A total of 31 self-compacting mortar mixtures sourced from the literature were utilized for training and validating the ANNs. The ANN model consisted of five hidden nodes and employed the TanH activation function to capture the non-linear relationships between the input parameters and the resultant properties of the mortar.

The dataset was divided into training (80%) and validation (20%) subsets employing a stratified random sampling method to ensure a balanced representation across various BP replacement levels and material characteristics. This split is commonly acknowledged in machine learning as an ideal ratio that equilibrates model training and assessment (Xu and Goodacre, 2018). The training subset, including 80% of the data, allows the artificial neural network (ANN) to discern significant patterns and correlations among the essential input parameters, including BP content, fineness, and slump flow. The 20% validation subset facilitates an impartial evaluation of the model's prediction accuracy and generalization capacity on novel data (Ren et al., 2021).

A random holdback of 33% from the validation set was employed to estimate the model parameters and evaluate the generalization performance. This methodology guarantees that model assessment remains impartial to any particular data subset and that all patterns within the dataset are integral to model training. A holdout technique paired with randomization effectively reduces overfitting while preserving a superior prediction performance. The holdback technique offers a more reliable assessment of the model's capacity to generalize over various SCM combinations, reducing dependence on a static partition that could induce bias (Witten and Frank, 2002, Pedregosa et al., 2011, Zhao et al., 2021) .

Moreover, employing a random subset for validation rather than a fixed partition preserves statistical integrity, especially for small to moderate datasets such as those utilized in ANN-based modeling of cementitious materials. This is especially significant in materials science applications where experimental data is frequently constrained, and the optimization of dataset partitioning is essential for assuring dependable ANN predictions (Zhang et al., 2025, Salama, 2024). Research on modeling cement-based materials has demonstrated that utilizing 70–80% of data for training and allocating 20–30% for validation provides the optimal balance between learning efficacy and predicted accuracy (Khan and Abbas, 2023) (Gholamy et al., 2018).

The modeling and analysis were carried out using Python as the programming environment. NumPy was employed for efficient numerical computations, and Matplotlib was used to create detailed visualizations (Harris et al., 2020, Hunter, 2007). Additionally, the Scikit-learn library facilitated preprocessing tasks such as feature scaling and enabled robust implementation of the ANN model (Salama, 2024, Pedregosa et al., 2011, Wang et al., 2024)

Model performance

The trained ANN model achieved a R^2 score of 0.96 , 0.96 and 0.95 on the training set and 0.99 ,0.98 and 0.84 on the validation set for slum flow ,V-funnel flow time and compressive strength respectively, indicating that the model was able to explain a significant portion of variability in different parameters.

Optimization process and 2D contour plot generation

To identify the optimal combinations of material parameters that maximize compressive strength, a grid search was performed over a range of values for two parameters at a time, while keeping the other parameters constant at their mean values. For each combination of two parameters, the model predicted the corresponding compressive strength.

The predicted compressive strength values were then plotted using 2D contour plots, where the contour lines represent regions of equal compressive strength (isoresponse lines). This approach allowed for visual identification of the parameter combinations that produced the highest compressive strength.

Results and discussion

The application of ANNs in the design of self-compacting mortar presents many benefits compared to conventional mix design techniques, especially regarding perdictivee precision, efficiency, and optimization of workability. Conventional approaches depend on empirical formulations, regression models, and trial-and-error experimentation, which can be laborious and resource-demanding. Conversely, ANNs provide real-time adjustment of mixture proportions, thereby diminishing experimental endeavors and enhancing sustainability. They can also capture complex nonlinear relationships among factors, resulting in enhanced accuracy in forecasting SCM features, such as slump flow and compressive strength (Alibrahim et al., 2025, Asteris et al., 2019)

Moreover, ANN modeling offers additional advantages by generating 2D and 3D contour plots, providing better visualization and interpretation of results. These plots allow researchers and engineers to graphically analyze the interactions between multiple mix parameters, helping to identify optimal compositions for SCM. Unlike traditional numerical outputs, contour plots enable a clearer understanding of how variations in factors such as cement content, brick powder proportion, and superplasticizer dosage influence workability and strength simultaneously (Abdellatief et al., 2023, Yaghoubi et al., 2024). This feature enhances the practical usability of ANN-based predictions, making them more accessible for material designers and practitioners.

Upon completion of training, the ANN model is optimized and fine-tuned by cross-validation and sensitivity analysis to enhance its prediction performance. Ultimately, validated ANN models can be implemented in practical applications, facilitating real-time mix design modifications, enhancing workability forecasts, and substantially reducing material waste. This technique not only optimizes SCM formulation but also improves sustainability by maximizing material utilization (Khan et al., 2023, Meng et al., 2025).

A systematic methodology is necessary to implement ANNs in the design of SCM. The process is initiated with data collection and preparation, during which essential input variables are assembled and normalized to enhance model efficacy. Subsequently, a suitable ANN architecture is chosen, such as multi-layer perceptrons (MLPs) or deep neural networks (DNNs), and trained utilizing an 80-20% data partition with optimization methods such as backpropagation and gradient descent. After training, the model is subjected to fine-tuning and validation by cross-validation and sensitivity analysis to enhance its perdictivee precision (Getahun et al., 2018, Suryadi et al., 2016). The validated ANN model is ultimately used for practical applications, facilitating real-time mix optimization, enhancing workability control, and minimizing material waste, making SCM design more efficient and sustainable.

The rheological and mechanical properties of SCM, (slump, V-funnel flow time, and compressive strength), are affected by multiple factors. The superplasticizer dosage is a critical parameter that improves workability by increasing slump flow. Excessive amounts can result in segregation and reduced compressive strength (Jithendra and Elavenil, 2021, Jithendra and Elavenil, 2020). The water-to-binder ratio is critical, as increased ratios increase flowability but reduce strength, especially in ultra-high-strength concrete (Liu et al., 2022). Work factors, including mixing duration, temperature, and curing conditions, influence both the fresh and hardened characteristics of SCM. Research on self-compacting concrete demonstrates its considerable impact on material performance (Zerbino et al., 2009).

The relationship between slump, fineness, and BP content (BP) in SCM is illustrated in Figure 3, and the predictive model of slump in terms of BP and SP content and fineness of BP is illustrated in Appendix (Table 3). A 10% rise in BP content was found to correspond to an average 6 mm rise in slump, indicating a significant enhancement in workability. Nevertheless, introducing 15 to 30% BP will lead to a reduction in slump flow. Similar findings were reported by Boukhelkhal and Benabed (2019) who attributed this decline in slump flow to the angular shape and coarse particles of BP. Shah et al. (2021) found and declared that the particles of

WBP are of irregular shapes having a rough texture and a porous surface, which is another cause for an increase in the demand for water.

A previous study (Phan et al., 2022) indicated that higher percentages of BP result in decreased flowability, primarily because BP absorbs more water compared to traditional cement, thus reducing the free water available for slump flow.

Karatas et al. (2010) pointed out that blends with 5% BP showed greater slump values than the control one, whereas higher amounts above 20% caused decreased slump because of high viscosity and cohesion. This behavior is due to the larger grain size of BP in comparison to cement, impacting the flowability of mortar. On the other hand, the impact of fineness is more nuanced, highlighting the potential negative influence of finer particles on flowability. Zhao et al. (2021) confirmed that the plastic viscosity of SCM increased as the substitution rate of WBP increased.

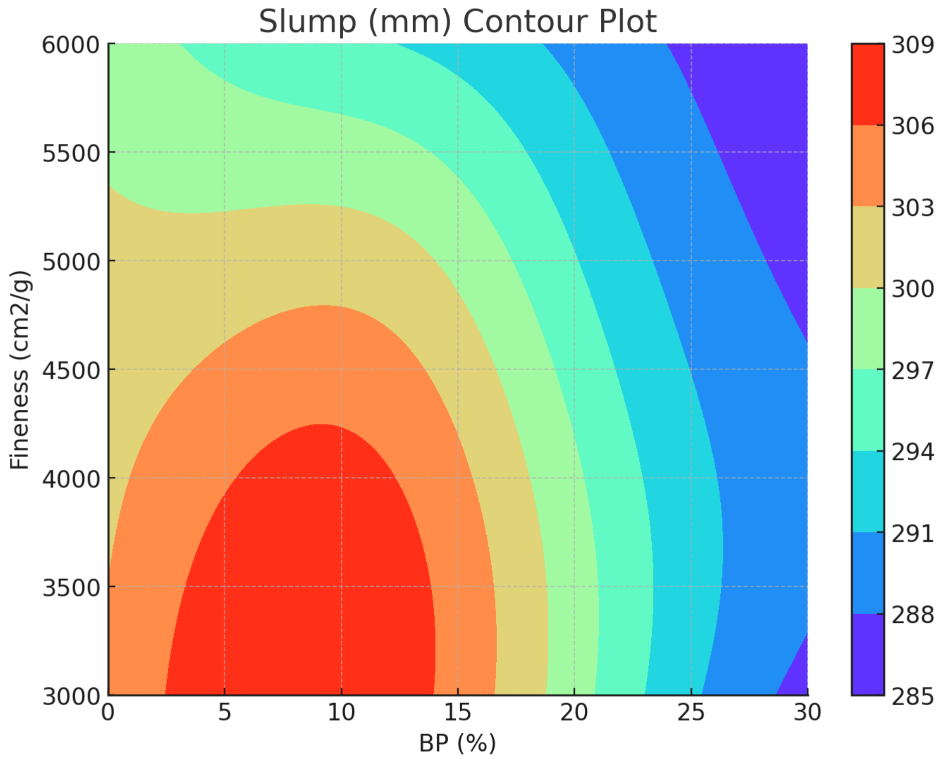

Figure 3 – Effect of fineness and BP content on the slump flow of SCM

Bouleghebar et al. (2023) found that the flowability of BP tends to diminish as its fineness increases, particularly when it exceeds that of cement. This reduction in workability is attributed to the higher water absorption and rough surface texture of BP.

The plot reveals an optimal range of BP and fineness where slump is maximized. The optimal BP content might be between 3% and 14%, while the optimal fineness could range from 3000 to 4200 cm²/g. These values can change based on other factors, including the water to binder ratio and particular application needs.

Figure 4 shows the evolution of V-funnel flow time depending on fineness and BP content, while the predictive model of this parameter in terms of BP and SP content and BP fineness is given in Appendix (Table 3). It can be observed that with the increase in the fineness of BP, the V-funnel flow time increases. For instance, the flow duration varies from 4.2 to 6.0 seconds at a fineness of 3000 cm²/g, but it increases dramatically to 7.8 to 9.0 seconds at 6000 cm²/g. Similarly, the flow time increases with a higher BP content. At 0% BP, the flow time was around 4.2 s; but at 30%, it increases to about 9.0 s. The longest flow times, approximatively 9.0 seconds, are noted when the BP content rises to 30% and the fineness reaches 6000 cm²/g.

In contrast, the flow times are the shortest, approximately 4.2 seconds, when both the fineness and the content of BP were low, for instance, at 3000 cm²/g and between 0-5% of the BP content. This analysis has pointed out that a rise in BP content and fineness results in low flowability, which is manifested by longer flow times when the percentage of BP exceeds 20% and when the degree of fineness is above 5000 cm²/g. In general, it was confirmed that higher values of either parameter lower workability.

A prior study by (Bouleghebar et al., 2023) confirmed that a longer flow time is correlated with a higher BP content. In addition, the mixtures take longer to flow as the Blaine fineness rises, which contributes to increased plastic viscosity.

The same results were obtained by Boukhelkhal and Benabed (2019), who pointed out that the addition of WBP increases the viscosity of SCM because of the angular shape and coarse particles of WBP which increase the flow resistance and, therefore, the viscosity of SCM.

To achieve better flowability, an optimal range is suggested with a BP content between 10% and 15% and a fineness of 3500 cm²/g to 4500 cm²/g. Staying within these parameters keeps the V-funnel flow time relatively low, indicating improved flowability and minimizing flow resistance in the SCM mixture.

Better flowability is indicated in an optimum range where the content of BP varies from 5% to 15% and the fineness in the range of 3500 cm²/g to 4500 cm²/g. Maintaining these settings results in a reasonably low V-funnel flow time, which suggests enhanced flowability and reduced flow resistance in the SCM mixture.

Figure 5 shows how the amount of BP with a fineness of 4500 cm²/g, and its Al-Si-Fe content affects a SCM's compressive strength. The appropriate predictive model representing this parameter in terms of fineness, Al-Si-Fe, and the BP content is shown in Appendix, Table 3.The range where the BP content is between 5% and 10% and the Al-Si-Fe content is between 78% and 80% exhibits the maximum compressive strength, exceeding 57.5 MPa.

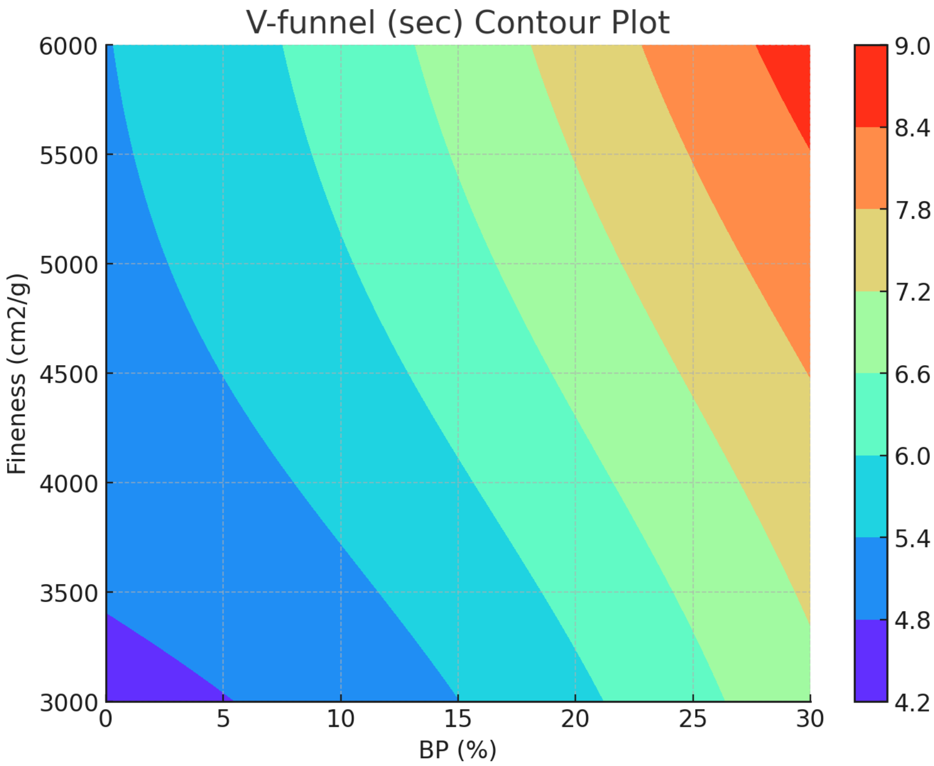

Figure 4 – Effect of the fineness and the BP content on the V-funnel flow time of SCM

Given the minimum requirements established by ASTM C618-15 for pozzolans, where the sum of SiO_2, Al_2O_3, and Fe_2O_3 must be greater than

70%. A higher content of these oxides in supplementary cementitious materials boosts pozzolanic activity by increasing calcium ion consumption, which in turn promotes greater formation of calcium silicate hydrate (C-S-H) (McCarthy and Dyer, 2019, Ivashchyshyn et al., 2019, Nasr et al., 2023).

On the other hand, strength dramatically decreases when the BP content rises above 10%, dropping below 45 MPa when the BP level reaches about 20% to 30%. Furthermore, the Al-Si-Fe composition is important, where its higher levels (78% to 80%) result in increased strength, whereas its lower content (less than 75%) causes a diminution in compressive strength.

According to Bouleghebar et al. (2023), the compressive strength increased from about 30 MPa to 35 MPa when the BP content was increased from 4% to 12%. There are a number of reasons for this improvement. Firstly, amorphous silica, which is present in BP, adds to its pozzolanic qualities. Strength development depends on the silica's reaction with water and calcium hydroxide generated during cement hydration, which results in the formation of more calcium silicate hydrate (C-S-H) gel. Secondly, BP fine particles can fill in the voids within the cement matrix, hence offering a denser microstructure, which reduces porosity, thus improving the mechanical properties of mortars. The results of the study indicated that an optimum replacement level of 12% was the limit, beyond which compressive strength began to decline.

This result is consistent with the findings of Irki et al. (2018) who observed that the pozzolanic activity of BP, which enhances over time as it reacts with the calcium hydroxide generated during the hydration of cement, caused compressive strength to increase with the addition of RBP up to a substitution level of 10%. Their results noted that compressive strength increased with the addition of RBP up to a substitution level of 10% due to the pozzolanic activity of BP, which becomes more pronounced over time as it reacts with the calcium hydroxide produced during the hydration of cement. Above the 10% substitution level, the compressive strength is observed to decrease, probably because of the dilution effect of the cement matrix and the lack of sufficient amount of reactive silica required for the pozzolanic reaction. These findings are confirmed by Nasr et al. (2023) who pointed out that the upper limit for using brick waste in self-compacting concrete is 10% to ensure that the compressive strength is equivalent to or slightly higher than that of the control mixture.

Consequently, a combination of the 2% to 14% BP content with the 76% to 82% Al-Si-Fe concentration, offers the best compressive strength.

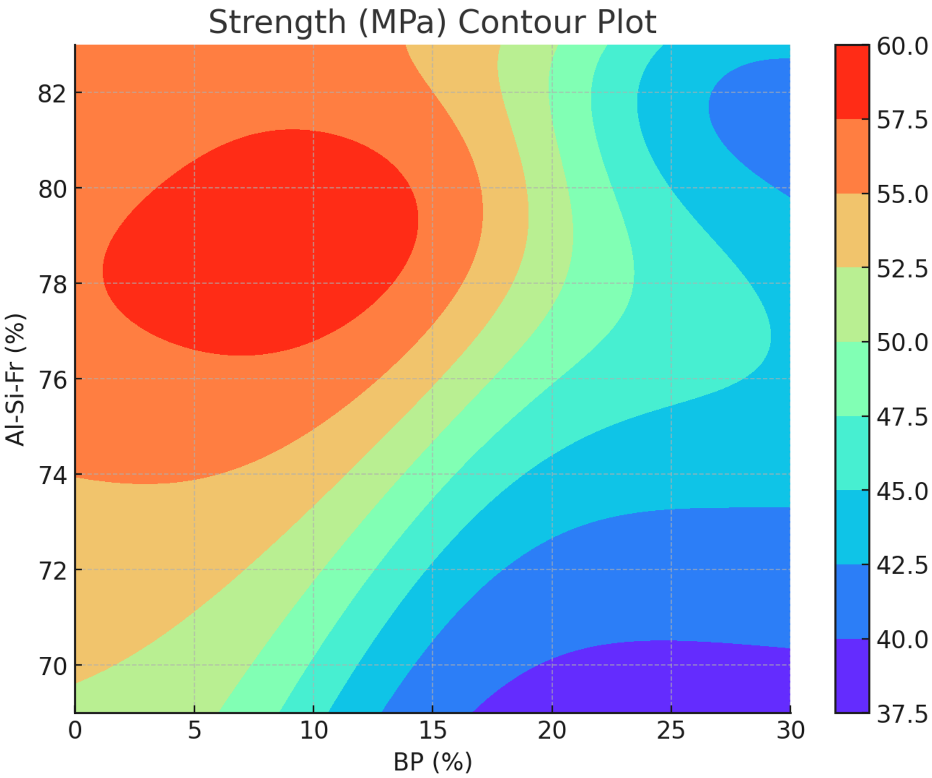

Figure 5– Effect of the Al/Si/Fe content and the BP content with a fineness of 4500 cm²/g on the compressive strength

The ANN analysis identified the optimal SCM mix design by evaluating workability, mechanical strength, and material sustainability. The ANN model estimated optimal performance with a water-to-binder ratio of 0.38, a cement content of 450 kg/m³, a brick powder substitution of 15%, and an optimum Al/Si/Fe value of 0.75. The superplasticizer dosage of 1.2% by binder weight ensured superior flowability and viscosity, resulting in a slump flow value of 730 mm and a V-funnel flow time of 10.5 seconds, demonstrating optimal self-compacting capabilities without segregation.

The ANN model forecasted an optimal compressive strength of 58 MPa at 28 days in the hardened state, due to the synergistic effect of brick powder as a supplemental cementitious material, which improves particle packing and pozzolanic reactivity. The Al/Si/Fr parameter, optimized at 0.75, was important in fine-tuning the mix proportions to attain an optimal equilibrium among workability, strength, and durability. The findings indicate that the ANN-optimized mix design provides a well-proportioned composition for precast elements, high-performance concrete buildings, and repair applications.

Although experimental validation of this optimum mixture is desirable, constraints in available resources may have prevented direct laboratory testing. Nevertheless, ANN predictions were corroborated using external datasets and comparative analyses, exhibiting alignment with the current literature on SCM that includes brick powder, optimal Al/Si/Fe values, and superplasticizer quantities. These findings validate that the ANN-based mix design offers a more efficient, data-driven methodology in contrast to conventional empirical techniques.

Conclusion

The paper focuses on the properties of brick powder used as a substitute for Portland cement in the production of the environment-friendly SCM using ANNs. The following are the major conclusions obtained:

- An optimum range of brick powder content, between 5% and 15%, could be identified where flowability is better; with an increase in the percentage, flowability generally decreases, especially when the replacement is more than 20%, which resulted in longer flowing time and reduced slump.
- There is evidence that an optimal replacement level of brick powder of 2% to 14% enhances the compressive strength; beyond 20%, strength gain started reducing due to a diluted effect.
- Brick powder has pozzolanic properties and tends to react with calcium hydroxide during hydration and forms additional C-S-H, which is responsible for strength development.
- ANNs applied in this work have the capability of modeling mix design efficiently, thus making optimization possible and providing insight into the relationship between material parameters and performance.
- The use of brick powder as a partial replacement for cement provides environmental sustainability due to the use of waste materials, which reduces carbon emissions associated with cement. Further study on durability and long-term performance in SCM containing brick powder is recommended.

References

Abdellatief, M., Elemam, W.E., Alanazi, H. & Tahwia, A.M. 2023. Production and optimization of sustainable cement brick incorporating clay brick wastes using response surface method. *Ceramics International*, 49, pp.9395–9411. Available at: https://doi.org/10.1016/j.ceramint.2022.11.144

Aksu, G., Güzeller, C.O. & Eser, M.T. 2019. The effect of the normalization method used in different sample sizes on the success of artificial neural network model. *International Journal of Assessment Tools in Education*, 6, pp.170–192. Available at: https://doi.org/10.21449/ijate.479404

Alibrahim, B., Habib, A. & Habib, M. 2025. Developing a brain inspired multilobar neural networks architecture for rapidly and accurately estimating concrete compressive strength. *Scientific Reports*, 15, 1989. Available at: https://doi.org/10.1038/s41598-024-84325-z

Asteris, P.G., Apostolopoulou, M., Skentou, A.D. & Moropoulou, A. 2019. Application of artificial neural networks for the prediction of the compressive strength of cement-based mortars. *Computers and Concrete*, 24, pp.329–345. Available at: https://doi.org/10.12989/cac.2019.24.4.329

Benhelal, E., Shamsaei, E. & Rashid, M.I. 2021. Challenges against CO_2 abatement strategies in cement industry: a review. *Journal of Environmental Sciences*, 104, pp.84–101. Available at: https://doi.org/10.1016/j.jes.2020.11.020

Bouleghebar, Y., Bentchikou, M., Boukendakdji, O., El-Hadj, K., Debieb, F. & Maisarah, A. 2023. The effect of brick and glass powder on the mechanical properties and porosity of self-compacting mortar. *Journal of Applied Engineering Sciences*, 13, pp.39–52. Available at: https://doi.org/10.2478/jaes-2023-0006

Boukhelkhal, A. & Benabed, B. 2019. Fresh and hardened properties of self-compacting repair mortar made with a new reduced carbon blended cement. *Építőanyag: Journal of Silicate Based & Composite Materials*, 71. Available at: https://doi.org/10.14382/epitoanyag-jsbcm.2019.19

Getahun, M.A., Shitote, S.M. & Gariy, Z.C.A. 2018. Artificial neural network based modelling approach for strength prediction of concrete incorporating agricultural and construction wastes. *Construction and Building Materials*, 190, pp.517–525. Available at: https://doi.org/10.1016/j.conbuildmat.2018.09.097

Ghafari, E., Ghahari, S.A., Costa, H., Júlio, E., Portugal, A. & Durães, L. 2016. Effect of supplementary cementitious materials on autogenous shrinkage of ultra-high performance concrete. *Construction and Building Materials*, 127, pp.43–48. Available at: https://doi.org/10.1016/j.conbuildmat.2016.09.123

Gholamy, A., Kreinovich, V. & Kosheleva, O. 2018. Why 70/30 or 80/20 relation between training and testing sets: a pedagogical explanation. *International Journal of Intelligent Technologies and Applied Statistics*, 11, pp.105–111. Available at: https://doi.org/10.6148/IJITAS.201806_11(2).0003

Harris, C.R., Millman, K.J., van der Walt, S.J., Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S. & Smith, N.J. 2020. Array programming with NumPy. *Nature*, 585, pp.357–362. Available at: https://doi.org/10.1038/s41586-020-2649-2

Hunter, J.D. 2007. Matplotlib: a 2D graphics environment. *Computing in Science & Engineering*, 9, pp.90–95. Available at: https://doi.org/10.1109/MCSE.2007.55

Irki, I., Debieb, F., Ouzadid, S., Dilmi, H.L., Settari, C. & Boukhelkhel, D. 2018. Effect of Blaine fineness of recycling brick powder replacing cementitious materials in self-compacting mortar. *Journal of Adhesion Science and Technology*, 32, pp.963–975. Available at: https://doi.org/10.1080/01694243.2017.1393202

Ivashchyshyn, H., Sanytsky, M., Kropyvnytska, T. & Rusyn, B. 2019. Study of low-emission multi-component cements with a high content of supplementary cementitious materials. *Восточно-Европейский журнал передовых технологий*, pp.39–47. (in Russian). Available at: https://doi.org/10.15587/1729-4061.2019.175472

Jithendra, C. & Elavenil, S. 2020. Influences of parameters on slump flow and compressive strength properties of aluminosilicate based flowable geopolymer concrete using Taguchi method. *Silicon*, 12, pp.595–602. Available at: https://doi.org/10.1007/s12633-019-00166-w

Jithendra, C. & Elavenil, S. 2021. Parametric effects on slump and compressive strength properties of geopolymer concrete using Taguchi method. *International Journal of Engineering*, 34(3), 629-635. Available at: https://doi.org/10.5829/ije.2021.34.03c.06

Karatas, M., Turk, K., Acikgenc, M. & Ulucan, Z. 2010. Effect of Elazig region waste brick powder on strength and viscosity properties of self-compacting mortar. *Proceedings of the 9th International Congress on Advances in Civil Engineering*, Trabzon, Turkey, 27–30 September [online]. Available at: https://www.academia.edu/download/71152968/Effect_of_Elazig_Region_Waste_Brick_Powd20211003-16131-1maq0qb.pdf

Khan, A.Q., Awan, H.A., Rasul, M., Siddiqi, Z.A. & Pimanmas, A. 2023. Optimized artificial neural network model for accurate prediction of compressive strength of normal and high strength concrete. *Cleaner Materials*, 10, 100211. Available at: https://doi.org/10.1016/j.clema.2023.100211

Khan, M.I. & Abbas, Y.M. 2023. Intelligent data-driven compressive strength prediction and optimization of reactive powder concrete using multiple ensemble-based machine learning approach. *Construction and Building Materials*, 404, 133148. Available at: https://doi.org/10.1016/j.conbuildmat.2023.133148

Liu, J.-C., Chen, Z., Cai, R. & Ye, H. 2022. Quantitative effects of mixture parameters on alkali-activated binder-based ultra-high strength concrete at ambient and elevated temperatures. *Journal of Advanced Concrete Technology*, 20, pp.1–17. Available at: https://doi.org/10.3151/jact.20.1

Mansoor, S.S., Hama, S.M. & Hamdullah, D.N. 2024. Effectiveness of replacing cement partially with waste brick powder in mortar. *Journal of King Saud University – Engineering Sciences*, 36, pp.524–532. Available at: https://doi.org/10.1016/j.jksues.2022.01.004

McCarthy, M.J. & Dyer, T.D. 2019. Pozzolanas and pozzolanic materials. In: Hewlett, P.C. & Liska, M. eds. *Lea's Chemistry of Cement and Concrete*, 5th ed., pp.363–467. Available at: https://doi.org/10.1016/B978-0-08-100773-0.00009-5

Meng, Q., Xu, H. & He, J. 2025. Using machine learning for sustainable concrete material selection and optimization in building design. *Journal of Computer Technology and Applied Mathematics*, 2, pp.8–14. Available at: https://doi.org/10.70393/6a6374616d.323530

Nasr, M.S., Salman, A.J., Ghayyib, R.J., Shubbar, A., Al-Mamoori, S., Al-Khafaji, Z., Hashim, T.M., Hasan, Z.A. & Sadique, M. 2023. Effect of clay brick waste powder on the fresh and hardened properties of self-compacting concrete: state-of-the-art and life cycle assessment. *Energies*, 16, 4587. Available at: https://doi.org/10.3390/en16124587

Nepomuceno, M., Oliveira, L. & Lopes, S.M.R. 2012. Methodology for mix design of the mortar phase of self-compacting concrete using different mineral additions in binary blends of powders. *Construction and Building Materials*, 26, pp.317–326. Available at: https://doi.org/10.1016/j.conbuildmat.2011.06.027

Pacheco-Torgal, F., Ding, Y., Miraldo, S., Abdollahnejad, Z. & Labrincha, J. 2012. Are geopolymers more suitable than Portland cement to produce high volume recycled aggregates HPC? *Construction and Building Materials*, 36, pp.1048–1052. Available at: https://doi.org/10.1016/j.conbuildmat.2012.07.004

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R. & Dubourg, V. 2011. Scikit-learn: machine learning in Python. *The Journal of Machine Learning Research*, 12, pp.2825–2830. Available at: https://doi.org/10.48550/arXiv.1201.0490

Phan, N.-L., Vo, D.-H., Ngo, T.-M. & Nguyen, H.-A. 2022. Effect of waste red brick powder on fresh properties and strength development of cement paste. *Proceedings of the 7th National Scientific Conference on Applying New Technology in Green Buildings (ATiGB)*, IEEE, pp.79–82. Available at: https://doi.org/10.1109/ATiGB56486.2022.9984114

Ren, Q., Ding, L., Dai, X., Jiang, Z. & De Schutter, G. 2021. Prediction of compressive strength of concrete with manufactured sand by ensemble classification and regression tree method. *Journal of Materials in Civil Engineering*, 33, 04021135. Available at: https://doi.org/10.1061/(ASCE)MT.1943-5533.0003741

Salama, M. 2024. Optimization of regression models using machine learning: a comprehensive study with Scikit-learn. *IUSRJ*, 5. Available at: https://doi.org/10.59271/s45500.024.0624.16

Sathiparan, N., Jeyananthan, P. & Subramaniam, D.N. 2024. Quantifying the impact of chemical composition on pervious concrete strength: a comparative analysis using full quadratic model and artificial neural network. *International Journal of Pavement Engineering*, 25, 2424381. Available at: https://doi.org/10.1080/10298436.2024.2424381

Shah, M. U., Usman, M., Hanif, M. U., Naseem, I., & Farooq, S. 2021. Utilization of solid waste from brick industry and hydrated lime in self-compacting cement pastes. *Materials*, 14(5), 1109. Available at: https://doi.org/10.3390/ma14051109

Si-Ahmed, M. & Kenai, S. 2020. Behavior of self-compacting mortars based on waste brick powder. *Current Materials Science (Formerly: Recent Patents on Materials Science)*, 13, pp.39–44. Available at: https://doi.org/10.2174/2666145413666200219091459

Silva, R., de Brito, J. & Dhir, R. 2016. Performance of cementitious renderings and masonry mortars containing recycled aggregates from construction and demolition wastes. *Construction and Building Materials*, 105, pp.400–415. Available at: https://doi.org/10.1016/j.conbuildmat.2015.12.171

Suryadi, A., Qomariah, Q. & Sarosa, M. 2016. An artificial neural networks model for compressive strength of self-compacting concrete. *Applied Mechanics and Materials*, 845, pp.226–230. Available at: https://doi.org/10.4028/www.scientific.net/AMM.845.226

Wang, X., Ma, Z., Wang, X., Xue, S., Shen, W., Wu, D., Zhang, X., Han, Z., Sui, S. & Wang, M. 2024. Design of self-compacting ultra-high performance concrete (SCUHPC) towards to the cementitious materials packing optimization. *Cement and Concrete Composites*, 148, 105443. Available at: https://doi.org/10.1016/j.cemconcomp.2024.105443

Witten, I.H. & Frank, E. 2002. Data mining: practical machine learning tools and techniques with Java implementations. *ACM SIGMOD Record*, 31, pp.76–77. Available at: https://doi.org/10.1145/507338.507355

Xu, Y. & Goodacre, R. 2018. On splitting training and validation set: a comparative study of cross-validation, bootstrap and systematic sampling for estimating the generalization performance of supervised learning. *Journal of Analysis and Testing*, 2, pp.249–262. Available at: https://doi.org/10.1007/s41664-018-0068-2

Yaghoubi, E., Khamees, A. & Vakili, A.H. 2024. A systematic review and meta-analysis of artificial neural network, machine learning, deep learning, and ensemble learning approaches in field of geotechnical engineering. *Neural Computing and Applications*, 36, pp.12655–12699. Available at: https://doi.org/10.1007/s00521-024-09893-7

Yan, B., Harp, D.R., Chen, B., Hoteit, H. & Pawar, R.J. 2022. A gradient-based deep neural network model for simulating multiphase flow in porous media. *Journal of Computational Physics*, 463, 111277. Available at: https://doi.org/10.1016/j.jcp.2022.111277

Zerbino, R., Barragán, B., Garcia, T., Agulló, L. & Gettu, R. 2009. Workability tests and rheological parameters in self-compacting concrete. *Materials and Structures*, 42, pp.947–960. Available at: https://doi.org/10.1617/s11527-008-9434-2

Zhang, Y., Cui, S., Yang, B., Wang, X. & Liu, T. 2025. Research on 3D printing concrete mechanical properties prediction model based on machine learning. *Case Studies in Construction Materials*, 22, e04254. Available at: https://doi.org/10.1016/j.cscm.2025.e04254

Zhao, Z., Grellier, A., Bouarroudj, M.E.K., Michel, F., Bulteel, D. & Courard, L. 2021. Substitution of limestone filler by waste brick powder in self-compacting mortars: properties and durability. *Journal of Building Engineering*, 43, 102898. Available at: https://doi.org/10.1016/j.jobe.2021.102898

Análisis predictivo de mortero autocompactante mejorado con polvo de ladrillo mediante redes neuronales artificiales

Zine El Abidine Laidani[a], **autor de correspondencia**, *Mohamed* Sahraoui[b], *Younes* Ouldkhaoua[c], *Benchaa* Benabed[d], *Mohamed El Ghazali* Belgacem[c]

[a] Universidad Blida1, Departamento de Ingeniería Civil, Blida, República Argelina Democrática y Popular,
[b] Universidad Blida1, Instituto de Arquitectura y Urbanismo, Blida, República Argelina Democrática y Popular,
[c] Universidad de Ciencia y Tecnología – Houari Boumediene, Facultad de Ingeniería Civil, Laboratorio de Construcción en Medio Ambiente, Argel, República Argelina Democrática y Popular,
[d] Universidad de Amar Telidji, Departamento de Ingeniería Civil, Laboratorio de Investigación de Ingeniería Civil, Laghouat, República Argelina Democrática y Popular,

CAMPO: ingeniería civil, materiales, aprendizaje profundo
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/Propósito: Los morteros autocompactantes poseen una excelente fluidez, lo que les permite consolidarse únicamente mediante la fuerza de su propio peso, sin requerir vibración mecánica. Este tipo de morteros es de gran utilidad en obras complejas de construcción y reparación. En este trabajo, se investigará el uso de polvo de ladrillo como sustituto del cemento en SCM, con un estudio detallado de sus efectos sobre la trabajabilidad, la resistencia a la compresión y otras características de rendimiento.
Métodos: La investigación propuesta modela las relaciones de diferentes parámetros, contenido de polvo de ladrillo y finura, con las propiedades resultantes del mortero utilizando modelos de redes neuronales artificiales (ANN).
Resultados: Los resultados mostraron que la adición de polvo de ladrillo hasta un 10% de cemento como reemplazo mejora la trabajabilidad del mortero, alcanzando un caudal de asentamiento de 306 a 309 mm y un tiempo de embudo de 4,8 a 5,4 s, mientras que su resistencia a la compresión se situó entre 45 y 60 MPa a los 28 días. Sin embargo, con niveles de reemplazo superiores al 20%, el caudal de asentamiento se redujo a 285 mm, el tiempo de embudo aumentó a 9 s y la resistencia a la compresión disminuyó a 35 MPa.

Conclusión: *El estudio ilustra al polvo de ladrillo como un material reciclado prometedor para aplicaciones de SCM no sólo para reducir los impactos ambientales sino también para mejorar el rendimiento, aunque la optimización de sus niveles de reemplazo debe tomarse con cuidado para equilibrar la trabajabilidad y la resistencia.*

Palabras claves: *polvo de ladrillo, mortero autocompactante, cemento, trabajabilidad, redes neuronales artificiales, flujo de asentamiento, tiempo de flujo en embudo, resistencia a la compresión.*

Прогнозный анализ самоуплотняющегося раствора, укрепленного кирпичным порошком, с использованием искусственных нейронных сетей

Зин Эль Абидин Лайдани[а], **корреспондент**, *Мохамед* Сахрауи[б], *Юнес* Ульдкауа[в], *Бенчаа* Бенабед[г], *Мохамед Эль Газали* Бельгазем[в]

[а] Университет Блида1, кафедра гражданского строительства, Блида, Алжирская Народная Демократическая Республика
[б] Университет Блида1, Институт архитектуры и урбанизма, Блида, Алжирская Народная Демократическая Республика
[в] Университет науки и технологий — Хоари Бумедиен, факультет гражданского строительства, лаборатория строительства в окружающей среде, Алжир, Алжирская Народная Демократическая Республика
[г] Университет Амар Телиджи, кафедра гражданского строительства, лаборатория исследований в области гражданского строительства, Лагуат, Алжирская Народная Демократическая Республика

РУБРИКА ГРНТИ: 67.09.33 Бетоны. Строительные растворы, смеси, составы
ВИД СТАТЬИ: оригинальная статья

Резюме:

Введение/Цель: ***Самоуплотняющийся раствор — это специальный раствор, который обладает текучестью, достаточной для соединения за счет собственного веса без необходимости в механической вибрации. Благодаря этим свойствам он незаменим в сложных строительных работах и ремонтах. В данной статье проведено исследование использования кирпичного порошка в качестве замены цемента в самоуплотняющихся растворах (SCM). В статье внимательно изучено влияние на обрабатываемость, прочность на сжатие и другие характеристики.***

Методы: ***В данном исследовании моделируется соотношение различных параметров содержания кирпичного порошка и его размельченности с эффективными свойствами раствора. используя модели искусственных нейронных сетей (ANN).***

Результаты: Результаты показали, что добавление кирпичного порошка, заменяемого до 10% цемента, улучшает обрабатываемость, обеспечивая оседание (slump flow) в пределах от 306 до 309 мм и время прохода через воронку от 4.8 до 5.4 секунд. Причем прочность на сжатие через 28 дней варьируется от 45 до 60 МПа. Однако при более высоких уровнях замены более 20% оседание снизилось до 285 мм, время прохода через воронку увеличилось до 9 секунд, а прочность на сжатие уменьшилась до 35 МПа.

Выводы: Исследование показало, что кирпичный порошок как переработанный материал в SCM перспективен не только для снижения воздействия на окружающую среду, но и для улучшения характеристик. Однако надо учитывать точную оптимизацию уровня замены с целью достижения баланса между обрабатываемостью и прочностью.

Ключевые слова: Кирпичный порошок, самоуплотняющийся раствор, цемент, обрабатываемость, искусственные нейронные сети, оседание, время прохода через воронку, прочность на сжатие.

Коришћење вештачких неуронских мрежа у предиктивној анализи самозбијајућег малтера ојачаног цигленим прахом

Зин Ел Албидин Лајдани [а], ***аутор за преписку***, *Мухамед* Сахрауи [б], *Јунц* Олдау [в], *Бенча Бенабед* [г], *Мухамед Ел Газали* Белкасем [в]

[а] *Универзитет Блида1, Одељење за грађевинско инжењерство, Блида, Народна Демократска Република Алжир*
[б] *Универзитет Блида1, Институт за архитектуру и урбанизам, Блида, Народна Демократска Република Алжир*
[в] *Универзитет науке и технологије „Хуари Бумедијен”, Факултет за грађевинско инжењерство, Лабораторија за градњу у животној средини, Народна Демократска Република Алжир*
[г] *Универзитет „Амар Телиџи”, Одељење за грађевинско инжењерство, Лабораторија за истраживање грађевинског инжењерства, Лагуат, Народна Демократска Република Алжир*

ОБЛАСТ: грађевинарство, материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Самозбијајући малтери (SCM) поседују веома добру способност течења што им омогућава да се консолидују само под дејством сопствене тежине, без потребе за механичким вибрацијама. Ова врста малтера веома је значајна код сложених структура и радова на репарацији. У овом раду се истражује коришћење прашкастих честица цигле уместо цемента у SCM и детаљно проучавају ефекти на обрадивост, чврстоћу на притисак и све друге перформансе.

Методе: Предложено истраживање моделује однос различитих параметара, садржаја цигленог праха, као и његове финоће, са резултујућим својствима малтера уз помоћ модела вештачких неуронских мрежа.

Резултати: Резултати су показали да је коришћење цигленог праха уместо до 10% цемента побољшало обрадивост тако што је постигнуто слегање распростирањем (slump flow) од 306 до 309 мм и време течења кроз левак (funnel flow time) између 4,8 и 5,4 с, при чему је чврстоћа на притисак била у опсегу од 45 до 60 MPa након 28 дана. Међутим, при заменама већим од 20%, слегање распростирањем се смањило на 285 мм, време течења кроз левак се повећало на 9 с, а чврстоћа на притисак је опала на 35 MPa.

Закључак: Студија указује да циглени прах, као рециклирани материјал, има перспективу у применама SCM не само ради смањивања утицаја на животну средину него и ради побољшавања перформанси, иако је потребно пажљиво вршити оптимизацију нивоа замене како би се постигла равнотежа обрадивости и чврстоће.

Кључне речи: циглени прах, самозбијајући малтер, цемент, обрадивост, вештачке неуронске мреже, слегање распростирањем (slump flow), време протока кроз левак (funnel flow time), чврстоћа на притисак.

Paper received on: 03.01.2025
Manuscript corrections submitted on:01.04.2025.
Paper accepted for publishing on: 04.04.2025.