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Research Article

Diabase Sludge as A New Eco-Friendly Waste for Use in Cement-Based Mortar

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Abstract

Appropriate waste management is recognised as being of pivotal significance for sustainable development. The utilisation of waste materials has the potential to reduce final costs and provide alternative raw materials for industrial sectors, such as construction. The ornamental rock industry is responsible for the generation of substantial amounts of waste. A number of studies have been conducted on the utilisation of stone sludge in mortars. However, no such studies were identified regarding diabase sludge from the ornamental sector, despite a substantial increase in diabase rock consumption attributable to its colour and physical properties. The impact of diabase sludge from a quarry in western Spain was examined as a cement replacement in mortar, with particular attention to consistency and fresh density. The diabase sludge, as collected (GDS), and the fraction below 63 µm (FDS) were evaluated. The experimental programme incorporated mortars with diabase sludge at varying replacement levels. The following two criteria were employed: Firstly, it is imperative to utilise the same flow values in order to guarantee uniform consistency across all mortars. Secondly, the water-to-binder (w/b) ratio must be maintained constant to evaluate the impact of diabase sludge on consistency. The mortars with 30% GDS, 20% FDS and identical flow values to the reference mortar were deemed to be the most suitable. The mortars with 20% GDS, 25% FDS and the same w/b ratio as the reference mortar have flow values that are similar.

Keywords: *Consistency; Diabase Sludge; Ornamental Rock; Mortar; Waste.*

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Introduction

At this time, approximately one-half of worldwide energy demand is generated by building construction, maintenance and conservation (Wang et al., 2018). Cement is a pivotal construction material that is extensively utilised on a global scale. Its production is recognised as a highly energy-intensive process (Medina et al., 2019). It is estimated that the manufacture of cement accounts for approximately 12-15% of industrial energy consumption (Souto-Martinez et al., 2018) and 10% of global CO_2 emissions (Snellings et al., 2017), due to the high temperatures (approximately 1450°C) required for the process. Consequently, the concept of sustainable development has reinvigorated the pursuit of reducing the cement content of cement-based materials, such as mortar. Mineral admixtures, including but not limited to fly ash, limestone powder, natural pozzolans and silica fume, have been utilised to substitute a proportion of the Portland cement in mortars (Cyr et al., 2005; Hossain et al., 2016; Siddique & Chahal, 2011). Nevertheless, the continuously increasing demand for mineral admixtures has resulted in a significant shortage of traditional mineral admixtures. It is imperative to contemplate alternative solutions and innovative approaches, in addition to investigating the potential of other mineral admixtures (Laibao et al., 2013).

The dimension stone industry is responsible for the generation of substantial volumes of waste, encompassing solid waste (predominantly arising from extraction processes) and moist fines or sludge (mainly produced during transformation stages). The management of substantial quantities of sludge can present significant challenges for its producers. The accumulation of this type of waste gives rise to a range of environmental, economic and health problems. The practice of disposing of waste by dumping it into rivers and lagoons is not an environmentally sound solution, and landfills are associated with significant drawbacks. As Mármol et al. (2010) reported, the processes of transporting and dumping waste in landfills involve substantial costs. Furthermore, over time, the water contained within the sludge evaporates, resulting in the formation of a fine powder that can be transported by the wind as suspended particles. It has been demonstrated that these air-suspended fine powders can be readily inhaled by humans, with the potential to induce severe respiratory diseases, visual and skin disorders among local populations (Mashaly et al., 2018). However, stone sludge, due to its fineness, can adequately fulfil the requirements to serve as an inert mineral admixture (filler) to reduce cement consumption in mortar (Gehlot & Shrivastava, 2024).

There are studies on mortars containing marble, limestone, granite and basalt sludge as alternatives to cement, but not on mortars with diabase sludge, despite the fact that diabase is present on all five continents and is often used in construction due to its colour and excellent mechanical properties. Diabase is an intrusive igneous rock, characterised by distinctive properties that differentiate it from other common igneous rocks, such as granite and basalt. In consideration of its substantial specific surface area and acidic chemistry, diabase sludge has the potential to function as a mineral admixture in mortar (Pacheco-Menor et al., 2025).

In view of the paucity of research conducted on mortars containing diabase, the performance of mortars comprising granite or basalt can be utilised as a basis to elucidate that of this novel mineral admixture. A plethora of studies have been conducted on the impact of incorporating granite and basalt sludge as mineral admixture in cement pastes or mortar mixes on their consistency and fresh density. In general, it can be determined that mortars composed of granite and basalt waste fines, when utilised as partial replacements for cement, demonstrate the capacity to either maintain or enhance the consistency of the reference mortar mix (Agrawal et al., 2021; Nascimento et al., 2020; Unčík & Kmecová, 2013; Woźniak et al., 2022).

The reasons for the presence of granite or basalt waste fines in cement paste or mortar mix can vary. One potential explanation for this phenomenon is that basalt waste fines possess a comparable surface to cement, thereby ensuring consistency remains unaltered despite an increase in stone fine waste content (Dobiszewska & Beycioğlu, 2017). Alternatively, granite sludge may exhibit low porosity, which could account for its minimal water requirement (Ramadji et al., 2020). As posited by Agrawal et al. (2021), the enhancement in workability of mortar mixes with granite sludge at 25% and 50% replacement levels is indicative of the disparity between the quantity of water necessitated for cement hydration and that absorbed by granite fine waste.

In most cases, replacing cement also results in a decrease in the hydration activity of the mortar, thereby enhancing its workability. As Nascimento et al. (2020) reported, an increase in the consistency index was observed for mortar mixes containing 15% and 20% granite sludge as a replacement for cement. For the other mixes (5% and 10%), no change in consistency index was observed in comparison to the reference. However, Medina et al. (2019) reported that mortar mixes with granite sludge at a constant water-to-cement ratio (w/b) exhibited a 7% decrease in mortar fluidity for 10% replacement and an 18% decrease for 35% replacement. The observed

behaviour was directly related to the jagged, irregular edges of the granite sludge particles, which increased the amount of water required to fill the inter-particle space. On the other hand, Mármol et al. (2010) observed an increase in the w/b ratio at a constant flow value of 167 ± 2 mm and at 10% and 20% replacement levels in mortar mixes with granite sludge. The w/b ratio was maintained at 5% replacement. Mashaly et al. (2018) identified multiple factors contributing to the elevated water demand in cement paste when utilising granite sludge. The following aspects must be considered in order to obtain a comprehensive understanding of granite sludge: firstly, the rough and angular texture, as well as the particle size distribution; secondly, the higher specific surface area of granite sludge due to its higher water absorption capacity; and thirdly, the amount of free water filling the inter-particle space, as well as the amount of water adsorbed onto inner and outer pore walls.

With regard to fresh density, the extant literature is scant and frequently contradictory. The substitution of a proportion of cement for granite sludge has been demonstrated to enhance the fresh density of the resultant mortar mix in comparison to the reference material. In the event of granite sludge comprising a smaller fraction than cement, the replacement of the former with a material comprising a smaller fraction will result in an increase in packing density. The incorporation of granite sludge has been demonstrated to effectively fill the voids between sand and cement, thereby enhancing the overall bulk density of the material (Nascimento et al., 2020; Woźniak et al., 2022). Woźniak et al. (2022) found that the highest density was achieved in the mortar mix with a 10% replacement of cement with granite fine waste, among all evaluated replacements (0%, 5%, 10% and 15%). In contrast, Agrawal et al. (2021) reported an inverse relationship between the percentage of granite fine waste and the fresh density of mortar with 0%, 25% and 50% replacement. The presence of granite fine waste, characterised by its roughness and angularity, has been demonstrated to exert a significant influence on the fresh density of mortar mixes. The incorporation of angular granite fine-waste particles has been demonstrated to increase air content and voids in the mortar mixes, thereby reducing fresh density.

In this study, diabase sludge from the ornamental sector was investigated for the first time as a new mineral admixture to replace cement in mortar. Initially, the focus was on the physical properties and chemical compositions of the materials. Subsequently, an analysis was conducted to ascertain the effect of diabase sludge on mortar, with particular reference to consistency and fresh density.

Two fractions were evaluated: the diabase sludge as collected, referred as global diabase sludge (GDS) and the fraction below 63 μm, referred as fine diabase sludge (FDS). Moreover, two criteria were used: Firstly, constant flow values are required to ensure the same consistency is maintained in all mortar mixes. Secondly, a constant w/b ratio is necessary to evaluate the diabase sludge impact on the consistency of the mortar mixes.

Materials and Methods

Materials

Diabase Sludge

The diabase sludge utilised in this study was sourced from a dimension stone factory located in Villar del Rey (Badajoz) in Spain. The factory is equipped with an extraction and transformation process, and diabase sludge is generated from both of these processes. The diabase sludge under consideration was retrieved from the transformation process, specifically during the squaring stage. The waste was then transferred to the laboratory for further analysis. Prior to testing, the specimen was subjected to a heating process in a laboratory oven for a duration of 48 hours at a temperature of 100°C with the objective of removing moisture. The dried diabase sludge was then subjected to a process of crushing and manual milling in order to ensure the complete removal of any lumps. In order to ensure the complete removal of residual moisture, the diabase sludge was subjected to a further drying process in an oven at a temperature of 100°C for a duration of 24 hours. This was undertaken to ensure that the material reached a constant weight. Following this, the material was characterised and utilised in the production of mortar mixes.

In a previous study by Pacheco-Menor et al. (2025), an exhaustive characterisation of diabase sludge for use in mortar was conducted. The conclusion of these studies was that the diabase sludge under scrutiny was a filler material. Diabase sludge's particles demonstrate an irregular and uneven shape in the > 106 μm fractions and a coarse texture. Diabase sludge contains wood fibres (1%) and particles from slate rock (25%) in its composition. The fibres originate from wooden pegs that are utilised to prop the stone while it is being squared. The diabase sludge exhibited a specific density that approximated that of cements, with an increase in density observed as the fractions' size diminished. It has been demonstrated that the specific surface area of diabase sludge is greater than that of cements. The mineral and chemical composition of the diabase sludge does not interfere with cement formulations. Pozzolanic activity has been observed in the diabase sludge. The physical properties

of the diabase sludge are outlined in Tables 1 and 2 and Figure 1.

In order to reduce the variation in the quality of diabase sludge and eliminate the fibres, it was decided to sieve a part of the sample collected. A sieve with a mesh size of 0.063 mm was utilised to manually separate the particles that exceeded this size. The dry sieving process resulted in the removal of 19.3% of the original mass of the diabase sludge sample, consisting of particles larger than 0.063 mm and fibres. The diabase sludge's specific surface area is lower than that of sieved diabase sludge, owing to the fact that larger particles possess a more reduced surface area (Anicua Sánchez et al., 2009). Therefore, two fractions of diabase sludge were utilised in this study: the as-collected (GDS) and the fraction below 63 µm (FDS).

Table 1. Particle Size Distribution of Diabase Sludge.

No. sieve (mm)	**4**	**1.7**	**1**	**0.5**	**0.25**	**0.125**	**0.063**
Passing wt. (%)	100	99	98	97	96	85	80.7

Source: (Pacheco-Menor et al., 2025)

Table 2. Specific Density and Specific Surface Area of Diabase Sludge.

Properties	**Specific Density (kg/m^3)**	**Specific Surface (m^2/g)**	**Loose Bulk Density (kg/m^3)**
Diabase sludge	2964 $\pm$ 46	2.3401	1085

Source: (Pacheco-Menor et al., 2025)



(a) (b) (c)

Figure 1. Phase and Texture of Diabase Sludge: (a) Flaky, Irregular and Rough Particles; (b) Irregular and Rough Particles; (c) Rounded Particles (Pacheco-Menor et al., 2025)

Other Materials

In this study, CEM I 42.5 R supplied by SECIL GROUP was used as the reference binder, which complies with the EN 197-1 (2011). Siliceous sands, categorised as fine and coarse sands with sizes ranging from 0-2 and 0-4 mm, were used conforming to the specifications of standard EN 13139 (2002). Prior to their incorporation, all sands were subjected to a drying process at a temperature of 105 °C. Tap water, which is regularly drinkable and supplied by Empresa Portuguesa de Águas Livres (EPAL) in Portugal, was used in this study. The water met the stipulated requirements in Directive 98/83/EC (1998).

Experimental Programme

- The research was divided into two experimental stages, which were to be conducted in parallel. The objective of the research was to determine how replacing cement with diabase sludge at various percentages influences the performance of mortars in the fresh state. Preliminary tests were conducted on a reference mortar to ascertain the w/b ratio necessitated to attain a plastic consistency with a flow value of 170 mm, in accordance with EN 1015-6 (2007) and EN 1015-2 (2006). The w/b was determined based on EN 1015-3 (2001). The research process was conducted in two stages.

- In the initial stage of the study, a series of mortar mixes were examined, incorporating varying proportions of GDS and FDS, while maintaining the consistency of the reference mortar mix. The objective of this stage was twofold. Firstly, the objective was to analyse the w/b ratios required for each of the mortar mixes with different diabase sludge replacements and fractions. Secondly, the objective was to select the mortar mixes with the highest replacement of cement by GDS and FDS and an adequate w/b ratio. In order to establish the various w/b ratios, a comprehensive series of tests was conducted in accordance with the European Standard EN 1015-3 (2001). In order to ensure the comparability of the mortar mixes, the flow values were fixed in the spread range of 170 ± 2 mm. A stricter flow range was adopted in order to treat consistency as a constant factor and to determine the w/b ratios more accurately for each mortar.

- In the second stage of the experiment, a set of mortar mixes with varying replacement ratios of GDS and FDS, but with the same w/b as the reference mortar, were evaluated. The objective of this study was to ascertain the mortar mixes with the highest replacement levels of cement with GDS and FDS while maintaining adequate workability. The selected mortar mixes to be analysed in the next study (hardened properties of mortar using fractions of

diabase sludge) were based on the mortar's fresh properties.

Mix Proportions

The mixing procedure was conducted in accordance with the European Standard EN 196-1 (2016). In order to evaluate the viability of incorporating diabase sludge to replace cement in mortar mixes, 13 mortar mixes were tested, with a volumetric ratio of 1:1.5:1.5 (cement: 0-2 mm sand: 0-4 mm sand). The mortar mixes were identified as follows:

- Reference mortar (REFM);
- Mortar with GDS replacing 5% (wt.) of cement (MGDS5);
- Mortar with GDS replacing 10% (wt.) of cement (MGDS10);
- Mortar with GDS replacing 15% (wt.) of cement (MGDS15);
- Mortar with GDS replacing 20% (wt.) of cement (MGDS20);
- Mortar with GDS replacing 25% (wt.) of cement (MGDS25);
- Mortar with GDS replacing 30% (wt.) of cement (MGDS30);
- Mortar with FDS replacing 5% (wt.) of cement (MFDS5);
- Mortar with FDS replacing 10% (wt.) of cement (MFDS10);
- Mortar with FDS replacing 15% (wt.) of cement (MFDS15);
- Mortar with FDS replacing 20% (wt.) of cement (MFDS20);
- Mortar with FDS replacing 25% (wt.) of cement (MFDS25);
- Mortar with FDS replacing 30% (wt.) of cement (MFDS30).

Tests

Workability of Fresh Mortar

The assessment of workability quantifies the water content required to be added to the mortar in order to achieve a pre-defined flow value of fresh mortar, or to determine the flow value of a mortar mix. The consistency test was conducted in accordance with the European Standard EN 1015-3 (2001), which provides the requisite guidelines for the execution of such a test. The following criteria were taken into consideration: The flow value of the mortar mixes was determined as the mean value of the individual flow values from the two test samples. The individual flow values deviated from their mean value by less than 10%, indicating that the measurement was satisfactory. The results were recorded in millimetres to the nearest 1 mm.

Bulk Density of Fresh Mortar

It is imperative to ascertain the bulk density of fresh mortar, a task of particular relevance in the context of production control. This knowledge is instrumental in the calculation of the air content by gravimetric means. The test was conducted in accordance with the European Standard EN 1015-6 (2007). Two samples were utilised to evaluate the bulk density of fresh mortar. The following criteria were taken into consideration: The individual bulk density values deviate from their mean value by less than 10%. This indicates that the measurement is satisfactory. Furthermore, the results were recorded in kg/m³ to the nearest 10 kg/m³.

Results and Discussion

Workability of Fresh Mortar

Fresh Mortar Mixes at A Constant Flow Value

The w/b ratios and flow values from previous tests carried out to identify the w/b ratio at which the mortar mixes with GDS and FDS achieved flow values of (170 + 2 mm) are shown in Tables 3 and 4. The elevated number of tests necessary to ascertain the w/b ratio in mortar mixes with FDS at 25% and 30% replacement, in conjunction with variations exceeding 10% in certain samples, indicated the potential for segregation in the mortar mixes at these percentages. However, in the case of the mortar mixes with GDS, this performance was not observed. This finding is consistent with the results described below.

As demonstrated in Figure 2, there is a notable similarity in the behaviour of mortar mixes with GDS and FDS as cement replacement, with a constant flow value being maintained. A positive trend in the w/b ratio is observed with increasing GDS and FDS content in both mortar mixes.

Table 3. W/b Ratios and Flow Values in Mortar Mixes with GDS

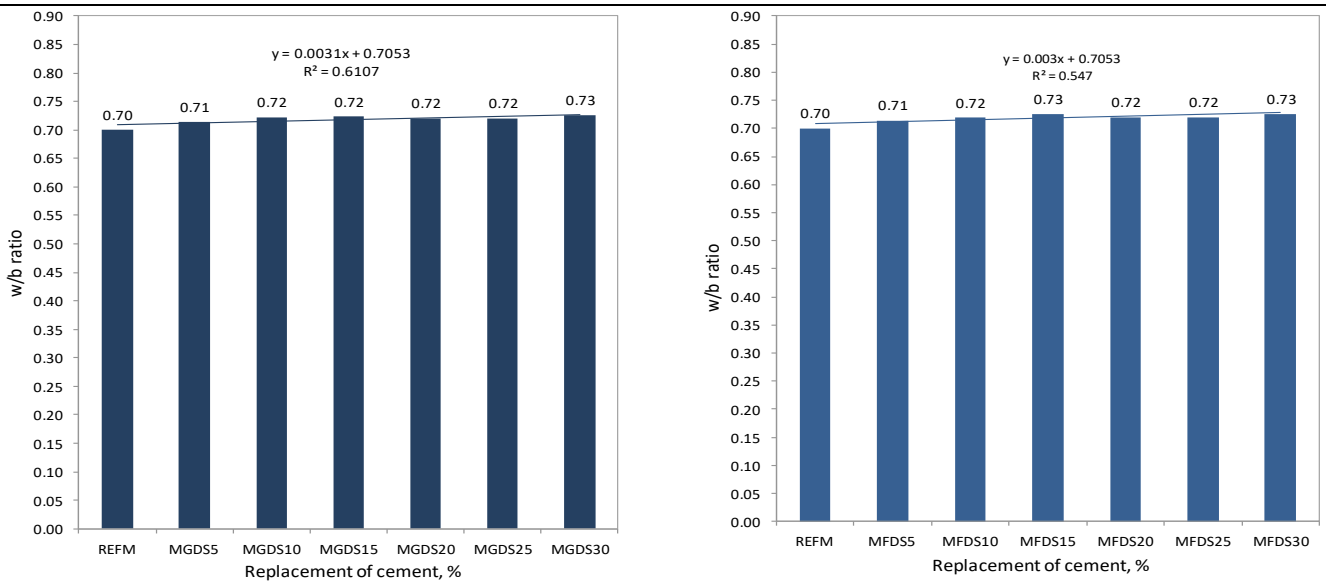
Mixes	w/b	Individual flow (mm)	Flow value (mm)	Variation (%)
REFM	0.70	167 174	170	4
MGDS5	0.714	169 171	170	1
MGDS10	0.717	164	-	-

Mixes	w/b	Individual flow (mm)	Flow value (mm)	Variation (%)
	0.722	169 172	170	2
MGDS15	0.787	> 200	-	-
	0.758	185	-	-
	0.746	182	-	-
	0.741	185	-	-
	0.729	178	-	-
	0.723	171 173	172	1
MGDS20	0.720	173 170	172	2
MGDS25	0.717	161	-	-
	0.722	172 175	174	2
	0.723	176	-	-
	0.720	171 174	172	2
MGDS30	0.726	175 170	172	3

Table 4. W/b Ratios and Flow Values in Mortar Mixes with FDS

Mixes	w/b	Individual flow (mm)	Flow value (mm)	Variation (%)
REFM	0.70	167 174	170	4
MFDS5	0.70	165	165	-
	0.71	169 170	169	1
MFDS10	0.86	> 200	> 200	-
	0.72	179	179	-
	0.717	169 166	167	2
	0.719	169 175	172	3
MFDS15	0.726	174 168	171	4
MFDS20	0.743	195	-	-
	0.741	181	-	-
	0.738	182	-	-
	0.733	175	-	-
	0.730	180	-	-
	0.729	186	-	-
	0.726	183	-	-
	0.720	172 164	168	5
MFDS25	0.717	170 161	166	5
		161 174	167	8
	0.722	159	-	-
	0.726	164	-	-
	0.732	172 178	175	4
	0.729	180	-	-
	0.723	174 181	177	4
	0.720	174 162	168	7
MFDS30	0.685	164	-	-
	0.694	170 152	161	11

Mixes	w/b	Individual flow (mm)	Flow value (mm)	Variation (%)
	0.697	159	-	-
	0.700	174 157	166	10
	0.703	152	-	-
	0.708	160	-	-
	0.713	168	-	-
	0.714	170 157	164	8
	0.720	163	-	-
	0.723	165	-	-
	0.726	169 169	169	0



(a) (b)

Figure 2. W/b Ratios of Fresh Mortar Mixes at Constant Flow Value: (a) with GDS; (b) with FDS

In relation to the mortar with FDS, a decline in the w/b ratio is observed for replacements 20% and 25%. This decline may be attributable to the occurrence of segregation. As stated by Nascimento et al. (2020), the raw material used in the production of binders is substituted with an inert one. In the case of GDS, the presence of fibres may possibly prevent segregation. It is acknowledged that fibres are capable of forming a reticular structure, thereby preventing segregation when incorporated into mortar mixes.

In accordance with the aforementioned data, the maximum percentages of GDS and FDS that can be utilised as alternatives to cement are 30% and 20%, respectively. It has been demonstrated that the incorporation of FDS in excess of 20% during the mixing process of mortar may result in segregation.

Fresh Mortar Mixes at Constant W/B

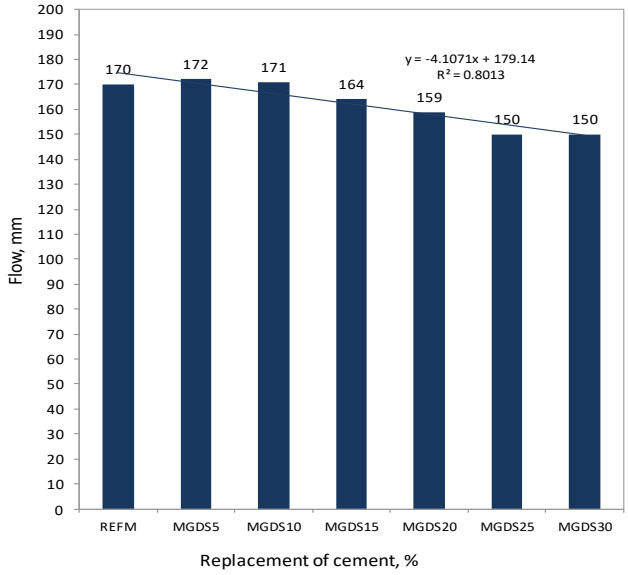
As demonstrated in Figure 3, a comparable trend is observed for mortar mixes incorporating GDS and FDS as cement substitutes. A decline in consistency is evident as the levels of GDS and FDS in both mortar blends increase, though this decline is more pronounced in the GDS mortar blend. As stated by Medina et al. (2019), an inverse relationship exists between consistency and the extent of granite sludge incorporation into the mortar, as discussed in Section 1. The morphology of the granite sludge particles has a direct impact on the required amount of water. It is evident that the reduction in fluidity of both mortar mixes, GDS and FDS, is less pronounced than that of granite sludge (Section 1). This phenomenon may be attributed to a combination of factors, including reduced porosity and decreased water absorption. As demonstrated by Alcalde Molero et al., (2004), dimension diabase stone exhibits a lower level of absorption and porosity in comparison to dimension granite stone.

Conversely, although a decline in consistency is evident in mortar mixes with GDS, a comparable flow value is attained for the 5% and 10% replacement levels (Figure 3a). This behaviour of the mortar mixes may be attributable to the larger particle size of GDS in comparison to FDS.

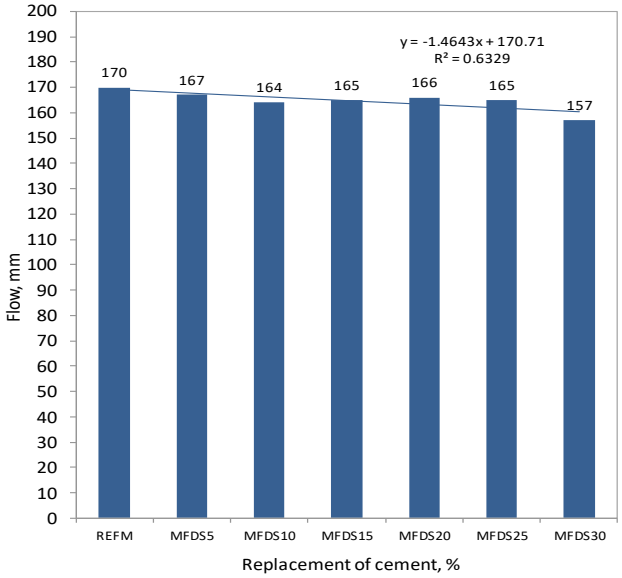
As stated in Section 1, several authors have documented outcomes which demonstrate comparable or enhanced consistency to that of the reference mortar, with replacement levels reaching as high as 15%. At a replacement level of 15%, the flow values of the mortar mix with GDS are lower than those of

the mortar mix with FDS. This phenomenon may be attributed to the presence of fibres. It has been established that as the percentage of fibres present in mortar mixes rises, the workability of the mix decreases.

It is highlighted that a slight increase in flow value was observed for mortar mixes with 15%, 20% and 25% FDS relative to the 10% replacement (Figure 3b). This minor increase may be attributable to a diminution in cohesion, precipitated by the substitution of a binder raw material with an inert one (Nascimento et al., 2020). However, this effect may be masked by increased water absorption at 30% replacement, as the DS content is very high.



(a)



(b)

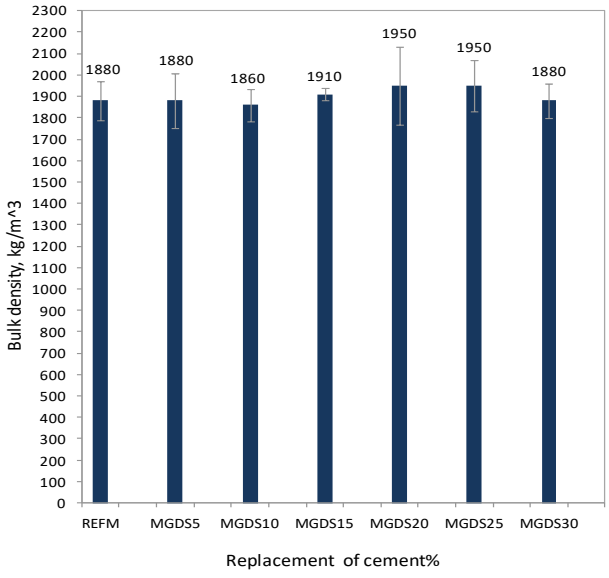
Figure 3. Flow Values of Fresh Mortar Mixes at Constant w/b Ratio: (a) with GDS; (b) with FDS

It is evident from the flow values obtained that the maximum percentages of GDS and FDS that can be utilised as cement replacement are 20% and 25%, respectively. The mortar mixes maintain a plastic consistency in accordance with EN 1015-6 (2007) and their flow values fulfil or are close to the range of 165-185 mm stipulated in EN 1015-2 (2007) for mortar mixes with a bulk density of fresh mortar greater than 1200 kg/m³.

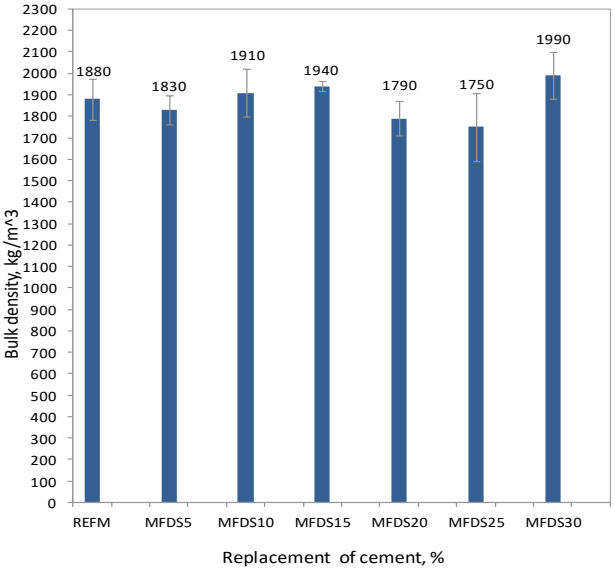
Bulk Density of Fresh Mortar

Fresh Mortar Mixes at A Constant Flow Value

As illustrated in Figure 4, the bulk density of fresh mortar mixes with GDS and FDS at a constant flow is presented, along with the corresponding absolute ranges. The fresh bulk density ranges from 1750 kg/m^3 to 1990 kg/m^3 in mortar mix with FDS. For mortar mixes with GDS, the range is 1860–1950 kg/m^3. As anticipated, the highest density is attained in the mortar mixes with FDS.



(a)



(b)

Figure 4. Bulk Density of Fresh Mortar Mixes at Constant Flow Value: (a) with GDS; (b) with FDS

No discernible trend in the bulk density of mortar with GDS and FDS is identified at a constant flow value (Figure 4). MFDS15 and MFDS30 attained the maximum density values, corresponding to the highest w/b ratios (0.73). The disparity in density between mortar mixes at 10% and 20–25% replacement, despite the uniform water-to-binder ratio (0.72), may be attributable to a heightened air content. The particles exhibited by diabase sludge are characterised by an irregular and uneven shape (Section 2). It can thus be concluded that the greater incorporation of diabase sludge has the capacity to increase the air content and voids in the mortar mixes, with the result that there is a decrease in fresh density (Agrawal et al., 2021).

On the one hand, the highest density value in mortar mixes with GDS is reached at 15% replacement and a w/b ratio of 0.73. However, the mortar mix with GDS at 30% replacement did not achieve the highest density at a w/b ratio of 0.73. The impact of elevated water levels, in conjunction with other variables, may be obscured by the voids that fibres may generate. The presence of fibres has been demonstrated to result in the formation of additional voids, which are known to occur as a consequence of microcavities being created within the interfacial transition zone that exists between the cement paste and the fibres (Iucolano et al., 2013). Conversely, an increase in mortar was observed with GDS at 15%, 20% and 25% replacement, along with a w/b ratio of 0.72. This phenomenon may be attributed to the higher density of FDS relative to GDS. Therefore, it can be deduced that the volume of the cement paste will be greater (Ngo et al., 2019). An increase in the volume of cement paste results in an increase in density.

Fresh Mortar Mixes at Constant W/B

As illustrated in Figure 5, the bulk density of fresh mortar mixes with GDS and FDS at a constant w/b ratio is presented, along with the corresponding absolute ranges. The bulk density of the mortar mix with FDS ranges from 1780 to 1930 kg/m^3. In the case of mortar mix with GDS, the range is 1800-1880 kg/m^3. The lower density of GDS in comparison to FDS may provide a rationale for this phenomenon. It is evident from Figure 5 that there is an absence of a discernible trend in bulk density in mortar with GDS and FDS at a constant w/b ratio. However, the bulk density values of the mortar mixes with diabase sludge are lower than those of REFM, except for the mortar mix with a 15% incorporation of FDS (Figure 5a). The most significant variation value (8%) of this one may provide a possible explanation. Conversely, a decline in the uniformity of mortar mix can result in the formation of voids. The lower density of the mortar mixes with diabase sludge at a constant w/b ratio in relation to REFM can be explained by the presence of these new voids.

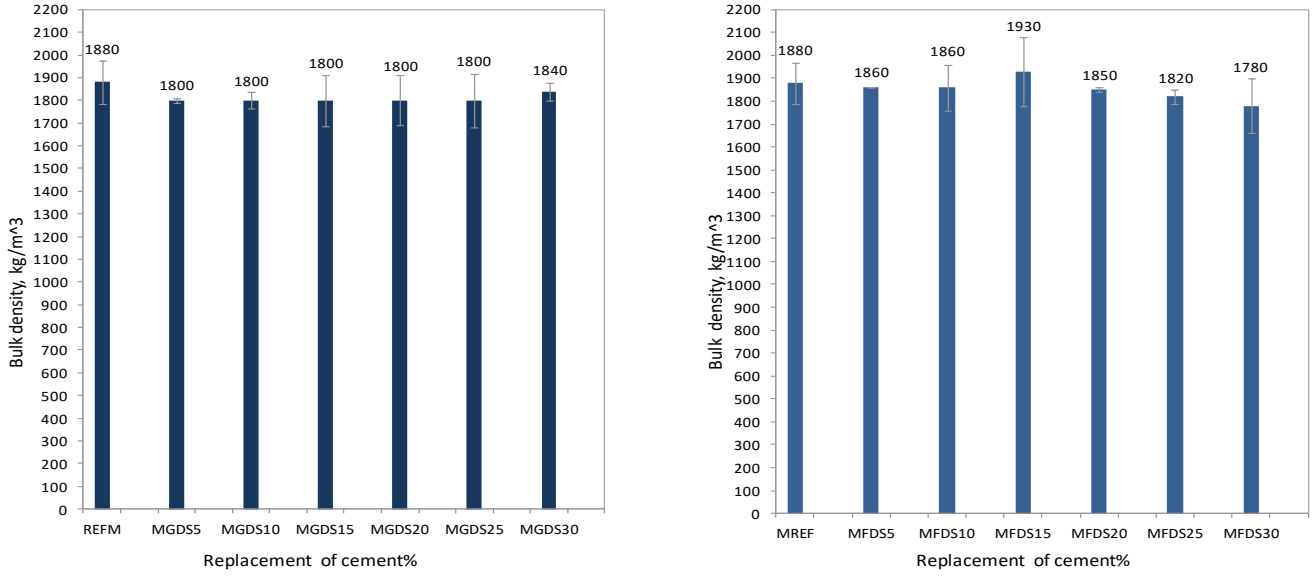


Figure 5. Bulk Density of Fresh Mortar Mixes at Constant w/b Ratio: (a) with GDS; (b) with FDS

Conclusion

The objective of this research is to analyse the potential of diabase sludge in terms of consistency and fresh density as a mineral admixture in the production of mortar mixes. For the purpose of this study, an experimental programme was conducted, which was divided into a number of parallel stages.

The following main conclusions were drawn for the consistency at a constant flow value:

- It is evident from the data that there is a positive trend of w/b ratio, which is indicative of an increase in both GDS and FDS in mortar mixes.
- It is evident that the maximum percentages of GDS and FDS that may be utilised as a substitute for cement are 30% and 20%, respectively.

- It is evident that no discernible trend in the bulk density is observed in mortars characterised by GDS and FDS. The highest density values in mortar mixes with GDS and FDS are attained at 15% replacement.

The following key conclusions were derived from the analysis:

- It is evident from the data that there is a negative trend of flow value with increasing levels of GDS and FDS in mortar mixes.
- It is evident that the maximum percentages of GDS and FDS that may be utilised as a substitute for cement are 20% and 25%, respectively.
- It is evident that no discernible trend in the bulk density of mortars with GDS and FDS is identified. In general, the bulk density of the mortar mixes with GDS and FDS is lower than that of REFM.

In conclusion, the results indicated that GDS can provide viable solutions for incorporation ratios up to 30% in terms of consistency, without the use of an admixture. Notwithstanding the encouraging outcomes of this study, it is recommended that further research be conducted in order to evaluate the impact of diabase sludge on the hardened mortar properties. In order to define the optimal replacements for the use of diabase sludge in mortar mixes, it is essential to consider physical properties such as flexural and compressive strength, and durability properties such as capillarity.

Declarations

Authors' Contributions

M.C.P.M: Methodology, Investigation, Writing of the original draft.

I.F.C: Conceptualization, Visualization, Supervision.

J.D.B: Writing -review & editing, Visualization, Supervision.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration on The Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were used in the preparation of this manuscript.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Ethics

This study did not involve human participants or animals; hence, no ethical approval was required.

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