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Research paper

# Fresh, mechanical and durability properties of sustainable cement grouts incorporating dredged materials from UAE dams

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ABSTRACT

The paper proposes the use of dam dredged materials (DDM) in the construction industry in the United Arab Emirates (UAE). The used DDM in this study were collected from a prominent dam in UAE. Four cement grout mixes were prepared by replacing aggregates with the following percentages of DDM: 0 %, 3 %, 5 % and 10 %. The fresh, mechanical and durability performance of the grout mixes were examined. The slump and rheology of the prepared grout mixes were measured over two hours, with one-hour intervals between two successive measurements. The rheology was assessed by conducting shear flow and stress growth tests. Further, air content, fresh bulk density and initial setting time were measured for all mixes. The mechanical properties were evaluated through measuring the compressive strength and hardened density at 7, 28, 56 and 90 days. Additionally, shrinkage, electrical conductivity and electrical resistivity were measured to assess the durability of the prepared mixes. The results showed that the dam dredged materials enhanced the mechanical and durability of the tested grouts. For example, the 28-day strength increased by approximately 40 % when DDM content was increased from 0 % to 10 %. Further, the DDM offset the shrinkage of the grouts, and shrinkage decreased with higher content of DDM. On the other hand, the cement grouts incorporating DDM were rated as medium resistance to chloride penetration after 90 days of curing. The cement grout mixes were implemented in two construction applications: tile adhesive and plaster. The samples for both applications showed favourable behaviour with no observed cracks after 11 months of exposure to harsh environmental conditions. The promising results of this study would contribute towards reducing the environmental impacts of dam dredged materials and preserving natural resources, leading to sustainable and economic benefits to the UAE.

## 1. Introduction

In hot arid climate countries, dams and reservoirs play crucial roles, in water management that help in confronting the challenges of scarcity of water resources [1–5]. In UAE, approximately 79 dams are contributing to a cumulative storage capacity of around 108 million cubic meters of water [2]. However, due to flush floods, large amounts of sediment materials are accumulated behind those dams in a natural process called siltation [6]. The accumulated materials affect the dams' operation and aquatic ecosystems. This leads to a reduction of dam's storage capacities, increasing the risk of floods. The dam's accumulated materials must be removed frequently to maintain the dam's functionality and longevity through a mechanical process called dam dredging [7,8].

The large amounts of accumulated sediment materials cause challenges to dams' operators that require wise management. Effective management of dredged sediments need adhering to environmental regulations and considering socioeconomic factors [9,10].

The disposal of dredged materials in landfills causes environmental and economic issues. As such, recycling these materials has numerous benefits, such as preserving natural aggregates, promoting industrial ecology, and reducing greenhouse gas emissions [(Intergovernmental Panel on Climate)] [11,7].

The dam dredged materials (DDM) have potential applications in

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two main areas: the construction industry and environmental engineering applications. For the construction industry, some of the potential applications are plaster and tile adhesion. Whereas for environmental engineering, possible applications are landfill, filtration material in wastewater treatment plants, soil aquifer treatment for wastewater reclamation and micropollutant removal.

As civil engineering sector is accountable for 6.4 % of direct $CO_2$ emissions and 12 % of indirect $CO_2$ emissions [12–15], utilizing recycled sediment in construction industry can help in mitigating its environmental impact. For example, the dredged materials can be used as supplementary materials replacing cement, reducing the $CO_2$ emission from the cement industry [9,16]. Other researchers proposed to use the fine sediment dredged from a reservoir as lightweight aggregates in concrete [17]. Recent study [18] has shown that dam dredged materials (DDM) can replace fine aggregates at substitution rates of 20–50 %, without significantly affecting mechanical properties, such as compressive and tensile strengths. However, an increased amount of DDM tends to reduce density, increase porosity, and negatively impact durability, evaluated by water absorption, shrinkage, and chloride permeability.

Despite the substantial volumes of dam dredged material (DDM) generated from periodic maintenance of UAE dams, current practices often involve disposal in landfills, posing environmental and economic challenges. There is a lack of systematic research on its potential reuse in construction applications. Moreover, no comprehensive studies exist that evaluate the fresh, mechanical, and durability properties of cement grouts incorporating DDM sourced from a UAE dam. This creates a critical knowledge gap in understanding its performance characteristics, potential benefits, and limitations, which hinders the development of standards or product certifications for its sustainable use.

The main objective of this study is to investigate the potential of utilizing the dam dredged materials in the construction industry. The DDM used in this investigation was collected from a prominent dam in the United Arab Emirates (UAE). Thus, the current study aims to introduce an environmentally friendly alternative for utilizing DDM, instead of disposing of it in landfills. The novelty of this research lies in the development of grouts incorporating UAE dam dredged materials that are suitable for plaster and tile adhesion. The study is the first in UAE to provide a detailed experimental work to investigate fresh, mechanical and durability properties of dam dredged materials from UAE dams to be utilized as sustainable materials in construction. This innovative approach contributes to advancing the field of sustainable construction in UAE by integrating the dam dredged materials in construction practices. The findings of this study will have a great impact on the construction industry in UAE and other countries willing to use dredged materials from dams as sustainable materials to reduce the environmental impact of dam siltation. This study will pave the way for standardizing the dam dredged materials and obtaining a product license (patent) to utilize it for grout plaster applications in construction. The methodology framework that was followed in this research is explained in details in the following methodology section.

## 2. Methodology

The research work in this paper was conducted in four stages as shown in Fig. 1. In the first stage, the raw materials including the dune

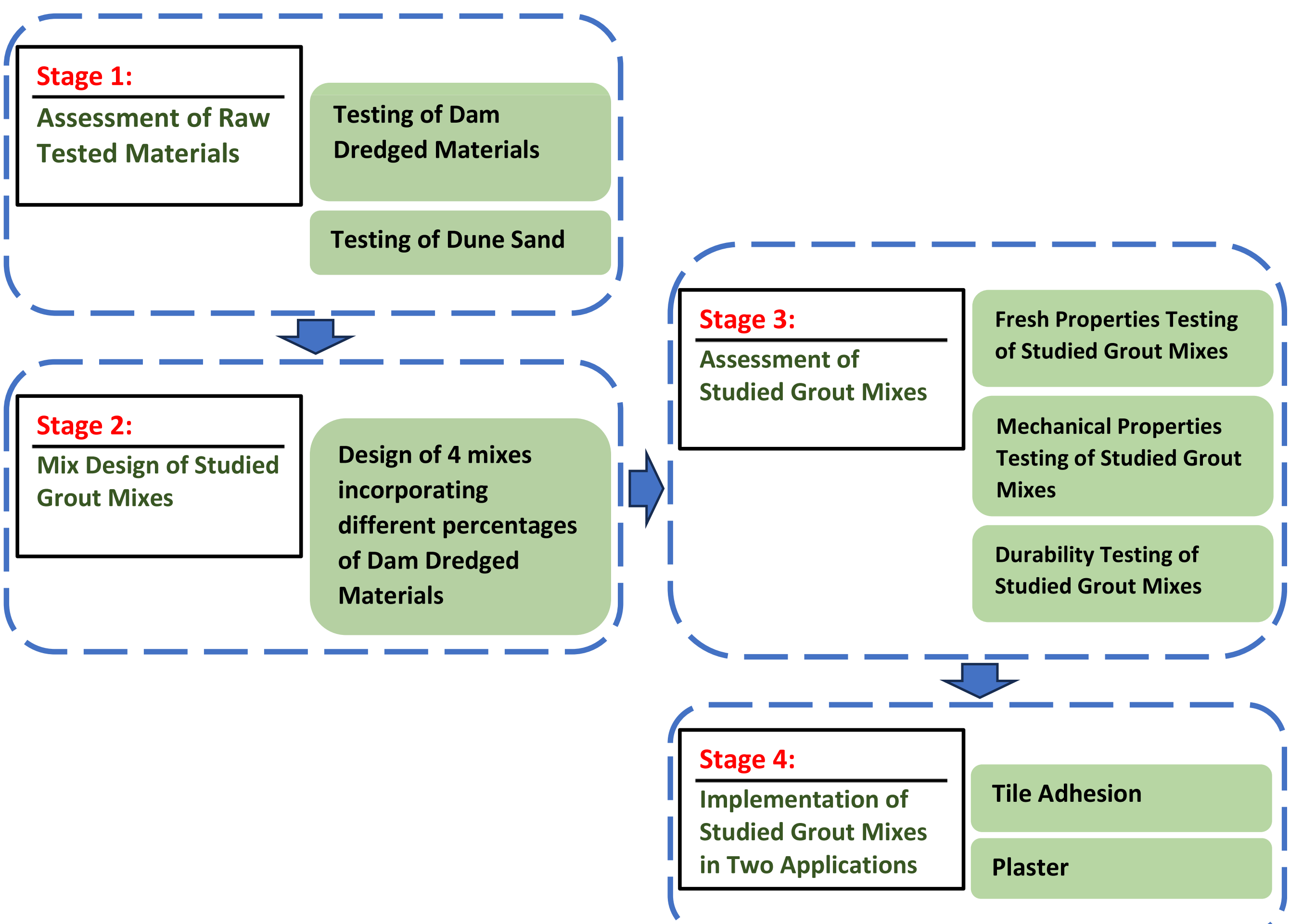



**Fig. 1.** Methodology Framework.

sand and dam dredged materials were tested and assessed. For the dam dredged materials, the following tests were conducted: particle size distribution, liquid limit (LL), plastic limit (PL), plasticity index (PI), particle density, water absorption and chemical analysis. The particle size distribution and water absorption tests were conducted on the dune sand.

In the second stage, the mix design of the studied grout mixes was prepared. The designed mixes incorporated four different percentages of dam dredged materials as partial replacements of dune sand. The assessment of the studied grout mixes was carried out in the third stage of this research through an extensive testing program including, testing fresh properties, mechanical properties and durability. In the fresh properties testing, the slump and rheological properties were measured over a two-hour period with one-hour intervals between two successive measurements. The measured rheology parameters included static yield stress, dynamic yield stress, plastic viscosity and thixotropy. Further, air content, fresh bulk density and initial setting time were measured for all mixes. The mechanical properties were evaluated by measuring the compressive strength and hardened density at 7, 28, 56 and 90 days. Shrinkage, electrical conductivity and electrical resistivity were also measured to assess the durability of the prepared mixes. After getting positive results from the assessment of the raw materials and the studied grout mixes (from stages 1 and 3, respectively), the fourth stage of this research concentrated on implementing the studied grout mixes in two applications: tile adhesion and plaster. This stage aimed to evaluate the suitability of the studied grout mixes to be implemented in the construction industry.

### 2.1. Stage 1: assessment of raw tested materials

Ordinary Portland cement Type I, natural dune sand and dam dredged materials were used in this investigation to prepare the cement grout plaster mixes. Fig. 2a shows the dam dredged materials and Fig. 2b shows the natural dune sand. The dredged sediment was obtained from a prominent dam in Al Fujairah, UAE.

In this stage of the research, several tests were conducted on the used dame dredged materials and dune sand to fully understand their properties and potential used in construction applications (Fig. 3).

The particle size distributions for the dam dredged materials and the dune sand are presented in Fig. 4. As shown, the dam dredged material has about 10 % Kaolinite, 5 % clay, 55 % silt and 30 % sand. Thus, the dam dredged materials have variable proportions of fine and relatively coarser particles. The sand and silt are dominant with a portion of about 85 % of the total material. Thus, this material can be classified as non-cohesive to semi cohesive material, and it can be used in construction applications, such as cement plastering and tile adhesion. Fine sand acts as a filler, improving cohesion, workability, and surface smoothness. While, silt content (if within controlled limits) enhances water retention, reducing the risk of early drying and shrinkage cracks.

Further, the liquid limit (LL) for the dam dredged materials is 32 %, indicating that the dam dredged materials have low to medium plasticity. Material with LL $<35$ % is considered low to medium plasticity [19]. Thus, the dam dredged material will flow under pressure at this moisture level, but will still hold some plasticity [19]. The plastic limit (PL) for dam dredged materials is 21 %. The value of PL of 21 % indicates that the dam dredged materials have a reasonable ability to retain moisture without losing cohesion entirely [20]. The plasticity index (PI), the difference between the LL and PL, is 11 % (low to medium), and thus the materials have limited shrink-swell potential. Therefore, dam dredged material is suitable to be used in construction applications, as it poses good stability, moderate water retention and minimal susceptibility to expansion or contraction by moisture fluctuation. The particle density of dam dredged materials is 2.6 mg/m$^3$ and it is 2.65 mg/m$^3$ for dune sand. Water absorption is 9.2 %, which is $>10$ times the water absorption of the dune sand (0.8 %). Further, chemical analysis of the dam dredge material indicates that it is slightly alkaline (pH =7.62). The water-soluble chloride content is low (0.03 %), thus the likelihood of efflorescence of degradation is low. Additionally, the organic matter content is 0.36 %, which is very low indicating that it doesn't have a risk of decomposition over time. Thus, the chemical results indicate that the dredged material from a UAE dam may be suitable to be used in construction applications such as plaster.

### 2.2. Stage 2: mix design of studied grout mixes

In this stage, four cement grout mixes were prepared incorporating dam dredged materials. The grout mixes were designed for the following potential applications: plaster and adhesive grout under tiles. The proportion of cement to fine aggregates (by weight) was 1:3. The constitutes of the four prepared mortar mixes are portland cement, fine aggregates (dune sand), dam dredged materials, water, and mid-range water reducing admixture. The water to cement ratio was 0.50. The proportioning of the constitutes of the first mix, which will be used as the reference mix (with 0 % replacement of dune sand with dam dredge), is in Table 1.

For the experimental mixes, the natural dune sand was replaced with dam dredged materials (DDM) of the following percentages: 3 %, 5 %, and 10 % by weight (Fig. 5). In order to select those DDM percentage, we went through an iterative process to find the optimal ratio for the DDM. The initial experiments have shown that DDM will provide improvement in grout properties at 3 % or more and values above 10 % DDM caused shrinkage cracks in the hardened grouts. The 0 % DDM was used as a baseline for comparison and identifying the effects of increasing the DDM percentages. This has also been confirmed by other studies. For instance, Zhang et al. [21] recommended the level for replacing the fine aggregates with silt (particle size less 75) is not to exceed 5 %; this is to

(a)

(b)

**Fig. 2.** Materials used in the grout mixes: (a) dam dredged materials (DDM) and (b) dune sand.

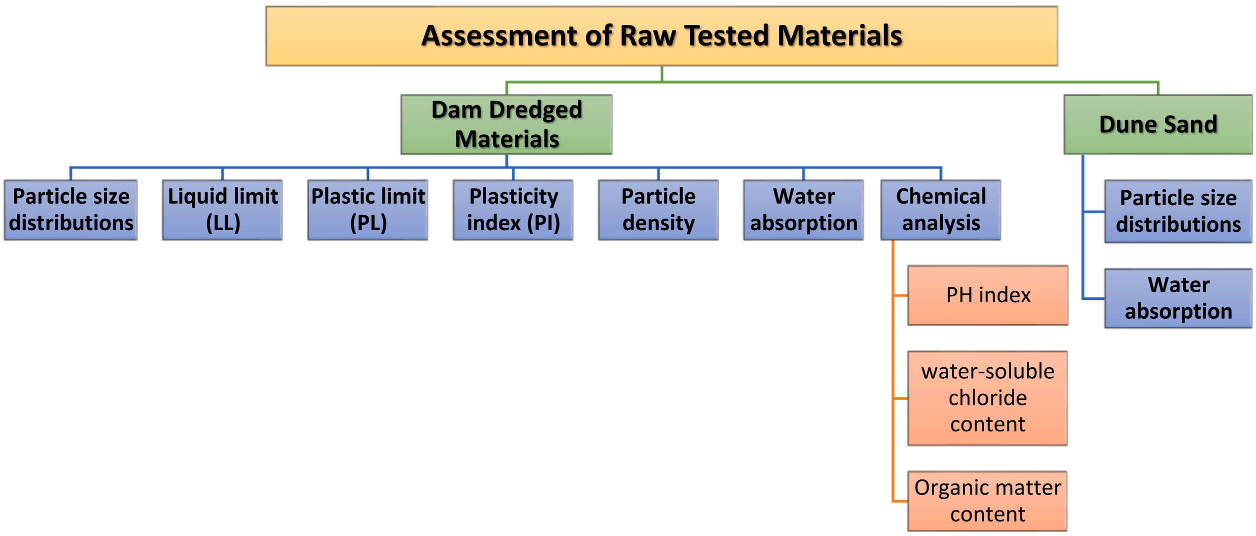



**Fig. 3.** Assessment of raw tested materials (dam dredged and dune sand).

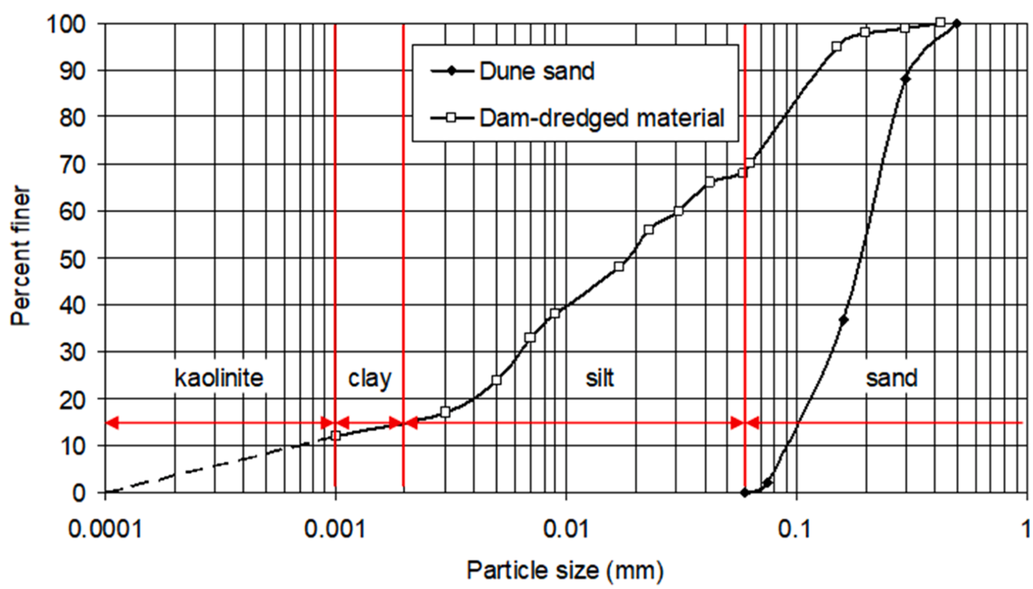



**Fig. 4.** Particle size distribution for dam dredged materials and dune sand.

**Table 1**
mix design of the reference mix (without dam dredged materials).

| Materials Type | Quantity (kg/m$^3$) |
|---|---|
| Dune Sand | 1440 |
| Type 1 OPC | 480 |
| Water | 270 |

avoid shrinkage or excessive slump loss. While Ke Zierkailedi et al. [22] incorporated 14 % of silt by mass of total aggregates in the grout mix. A study by [18] has shown that dam dredged materials (DMs) can replace fine aggregates at substitution rates of 20–50 % without significantly affecting mechanical properties, such as compressive and tensile strengths. However, increased DDM content tends to reduce density, increase porosity, and negatively impact durability indicators like water absorption, shrinkage, and chloride penetrability. Thus, the selected DDM percentages in this study were within the recommended range in the literature.

In this paper, the mix design for the cement grouts mixtures were developed using a systematic approach that balances both the functional and finishing properties of the material. The proportions of dam dredged materials were determined through a series of preliminary trials aimed at achieving the desired characteristics required for the investigated applications without compromising the workability of the grouts.

For proper mixing and processing, we adhered to standard grout mixing methods, following a well-studied sequence to achieve reliable mixing results. The dam dredged materials were pre-distributed with the dune sand in the dry phase to prevent clumping before the addition of cement. Thus, the dune sand and dam dredged material were initially dry mixed for 3 min. Then the cement was added and mixing resumed for an additional 2 min. Then water and superplasticizer were gradually added and mixing continued for an additional 3 min until a uniform consistent mix was obtained. The mixing speed of the mixer was about 35 rpm. To achieve the target slump (150 mm), the dosage of the mid-range water reducer was modified for each mix.

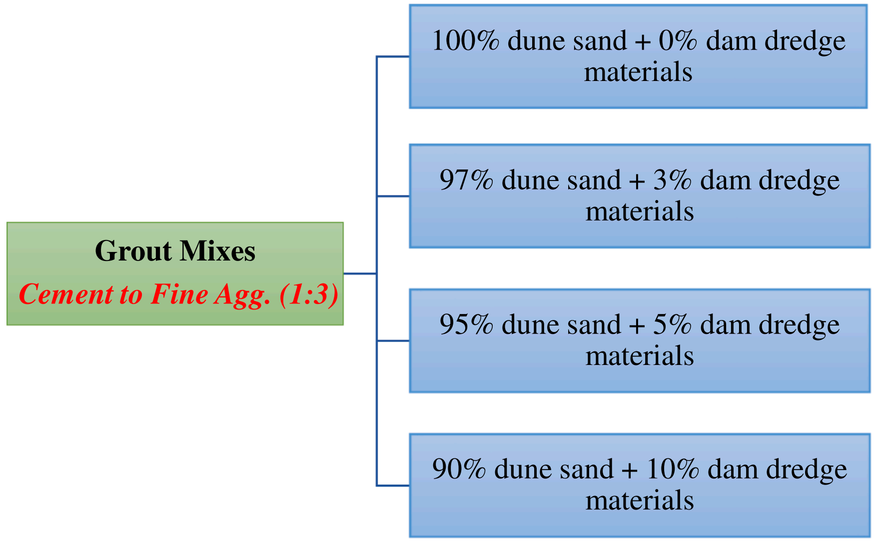



**Fig. 5.** Grout Mixes dam dredged material replacement percentage.

### 2.3. *Stage 3: assessment of studied grout mixes*

In this stage the four grout mixes that were proposed in the previous design stage were tested to assess their properties and suitability for construction applications. The testing and experimental work conducted on these mixes was done in three steps. First the fresh properties were investigated followed by the hardened properties and ending with the testing of the durability of these mixes (see Fig. 6).

### 2.4. *Stage 4: implementation of studied grout mixes on two applications*

In the fourth stage of this study, the grout mixes were implemented and studied incorporating them into two applications: tile adhesion and plaster.

## 3. Experimental work

### 3.1. *Fresh properties: testing of studied grout mixes*

The flowability of the prepared cement grout mixes was evaluated using the slump test according to ASTM C143 (Fig. 7a). The air content and bulk density were measured following ASTM C231 (Fig. 7b) and ASTM C138 (Fig. 7c), respectively.

The initial setting time for the prepared mixes was measured following ASTM C403 (Fig. 8a). The rheological properties of the mixes including static yield stress, dynamic yield stress, thixotropy and plastic viscosity were measured using an advanced concrete rheometer (ICAR) as shown in Fig. 8b

### 3.2. *Mechanical properties testing of studied grout mixes*

The mechanical properties that were tested in this step are the

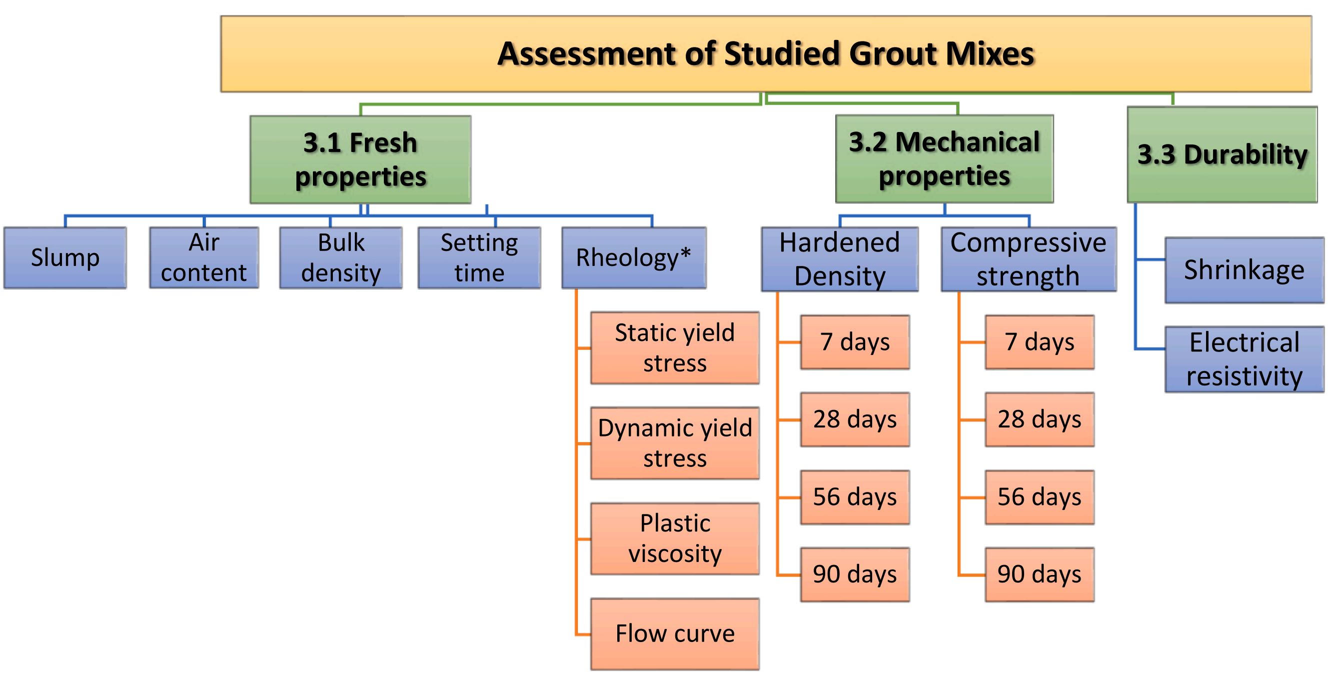



**Fig. 6.** The experimental matrix of the tested variables of the cement grouts.


(a) (b) (c)

**Fig. 7.** Fresh properties testing of the prepared grout mixes: (a) slump test, (b) air content and.

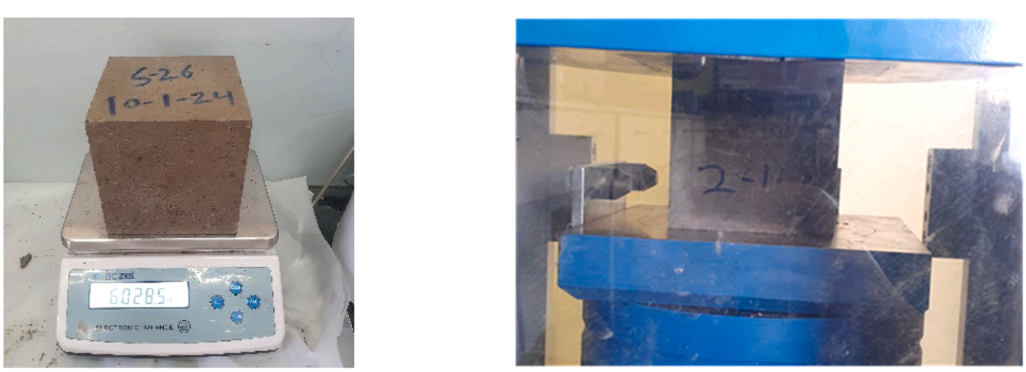
(a) (b)

**Fig. 8.** (a) Initial setting time test and (b) rheology test.

hardened density and compressive strength. Both properties were tested using 15 cm by 15 cm cubes (Fig. 9).

### 3.3. *Durability testing of studied grout mixes*

In this stage the durability properties that were tested are the electrical conductivity, electrical resistivity and shrinkage. The Merlin




(a) (b)

**Fig. 9.** (a) Hardened density and (b) Compressive strength test.

GRANDE equipment was employed to measure electrical conductivity and electrical resistivity according to (ASTM C1876 - 19, 2019). Also, cubic grout specimens of 150 mm were used to perform this test. The specimens were tested at saturated conditions [23,24]. Before conducting the electrical conductivity/ resistivity test, the sponges of both sides of the bulk conductivity cell were moistened with distilled water. To measure the electrical conductivity, the saturated-surface-dry cube was placed in the bulk conductivity cell. Then, an electrical current was applied to the specimen through an alternating squared shaped current source (Fig. 10a). The electrical conductivity measurement was in milli-Siemens per meter (mS/m). The conductivity results were converted to RCP value as per Merlin reference correlation. The test was conducted on specimens cured at 7, 28, 56 and 90 days.

The shrinkage test was conducted following ASTM C157. Mortar prims with dimensions of 25 mm (section) and length of 285 mm were used for shrinkage testing (Fig. 10b). After demolding, the tested prism was placed in water for 15 min, and then it was taken out of water. The excess water on the surface was wiped, and its length was measured (initial length). The specimen was placed back into the curing tank until the next readings (28, 56 and 90 days). The change in length at any age was calculated using Eq. (1).

$$(\Delta Lx) = \frac{\text{CRD} - \text{initial CRD}}{\text{G}} \times\ 100 \ldots (\Delta Lx) = \frac{\text{CRD} - \text{initial CRD}}{\text{G}} \times\ 100 \quad (1)$$

where,

$\Delta L_x$ = length change of specimen at any age, %
CRD = difference between the comparator reading of the specimen and the reference bar at any age, and $G$ = the gage length (285 mm)

## 4. Results and discussion

### *4.1. Fresh properties*

The required dosage of the superplasticizer (SP) to achieve the initial slump (150 mm) is shown in Fig. 11a. The greater the content of the dam dredged material, the higher the required dosage of superplasticizer (Fig. 11a). The required superplasticizer dosage increased from 1.1 % for 0 % dam dredged materials mix (reference mix) to 1.8 % for 10 % dam dredged material mix (Fig. 11a). The dam dredged materials in the cement grout initially holds water due to the capillary action of the silt [25]. As the grout with more content of dam dredged materials retains more water, it requires additional dosage to compensate for the shortage of free water due to the retained water.

Fig. 11b shows the results of air content (AC) versus the replacement levels of the dam dredged materials. It can be observed that the air content slightly increased with more replacement of the dam dredged materials.

Fig. 11c shows the fresh bulk density (BD) of the investigated mixes as a function of the dam dredged materials content. It can be observed that the replacement of dune sand with dam dredged materials showed a significant impact on the fresh density. The fresh bulk density increased sharply with an increased replacement level of the dam dredged materials. The fresh bulk density was 1670 kg/m$^3$ for the mix with zero dam dredged materials and increased to 1783 Kg/m$^3$ for the mix with a 10 % replacement level; the increase was about 7 %. This can be due to the fine particles, that fill the gap between coarse particles in the mortar matrix resulting in higher fresh density.

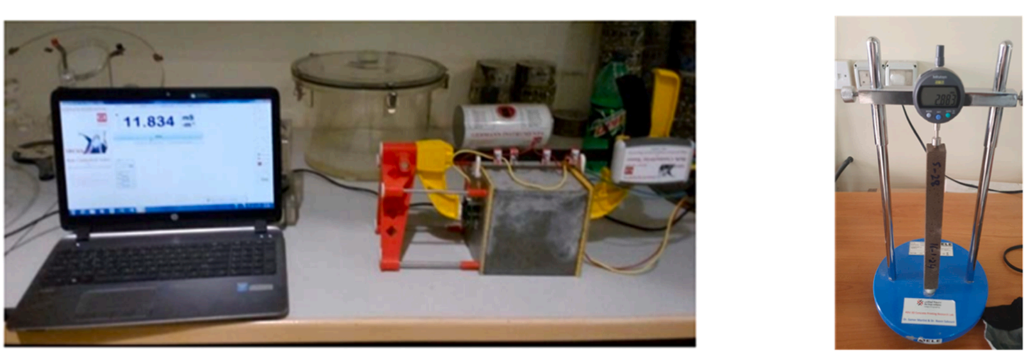
Fig. 11d shows the slump values (SL) for all grout mixes over 2 h. As shown in the figure, the initial slump was about 150 mm for all grout mixes. After one hour, the slump dropped to 130 mm for all grout mixes (for all dam dredged materials replacement levels). This indicates that the retained water, due to the earlier discussed silt capillary action, released gradually over the first hour. This release compensated for the reduction in workability with time, keeping consistent slump values over the silt content. After two hours, the slump consistently decreased with a higher content of dam dredged materials (Fig. 11d). This is because most of the capillary water in the grout was lost after 2 h by several factors: evaporation, absorption, and hydration. It can be concluded that the silt initially enhanced the workability of the grout for up to 1hr, but after 2hr a noticeable slump reduction was observed with a higher replacement level of the silt. The slump experiment, which is an indicator of pumping performance, has shown that the dosage of superplasticizer needs to be increased to achieve the required slump and in turn improve grout pumpability. It should be noted that segregation of the grout particles was not observed as segregation issues may take place if mixes contain large particles (e.g., gravel).

The results of the initial setting time for studied mixes are presented in Fig. 10e. The initial setting time decreased with a higher content of silt. The mix with 0 %, 3 %, 5 % and 10 % dame dredged materials content had an initial setting time of 535 min, 515 min 482 min, and 460 min, respectively.

### *4.2. Rheology properties*

#### *4.2.1. Grout rheology*

Rheological properties, particularly yield stress and plastic viscosity, play a crucial role in the practical handling of concrete. Lower yield stress and well-balanced viscosity improve the pumpability of concrete, reducing the pressure needed for pumping and minimizing risks of blockages or segregation [26]. These properties also enhance workability, allowing for smoother mixing, easier transport, and better shaping of the concrete without excessive water or admixtures.




(a) (b)

**Fig. 10.** (a) Electrical conductivity and resistivity test and (b) Shrinkage test.

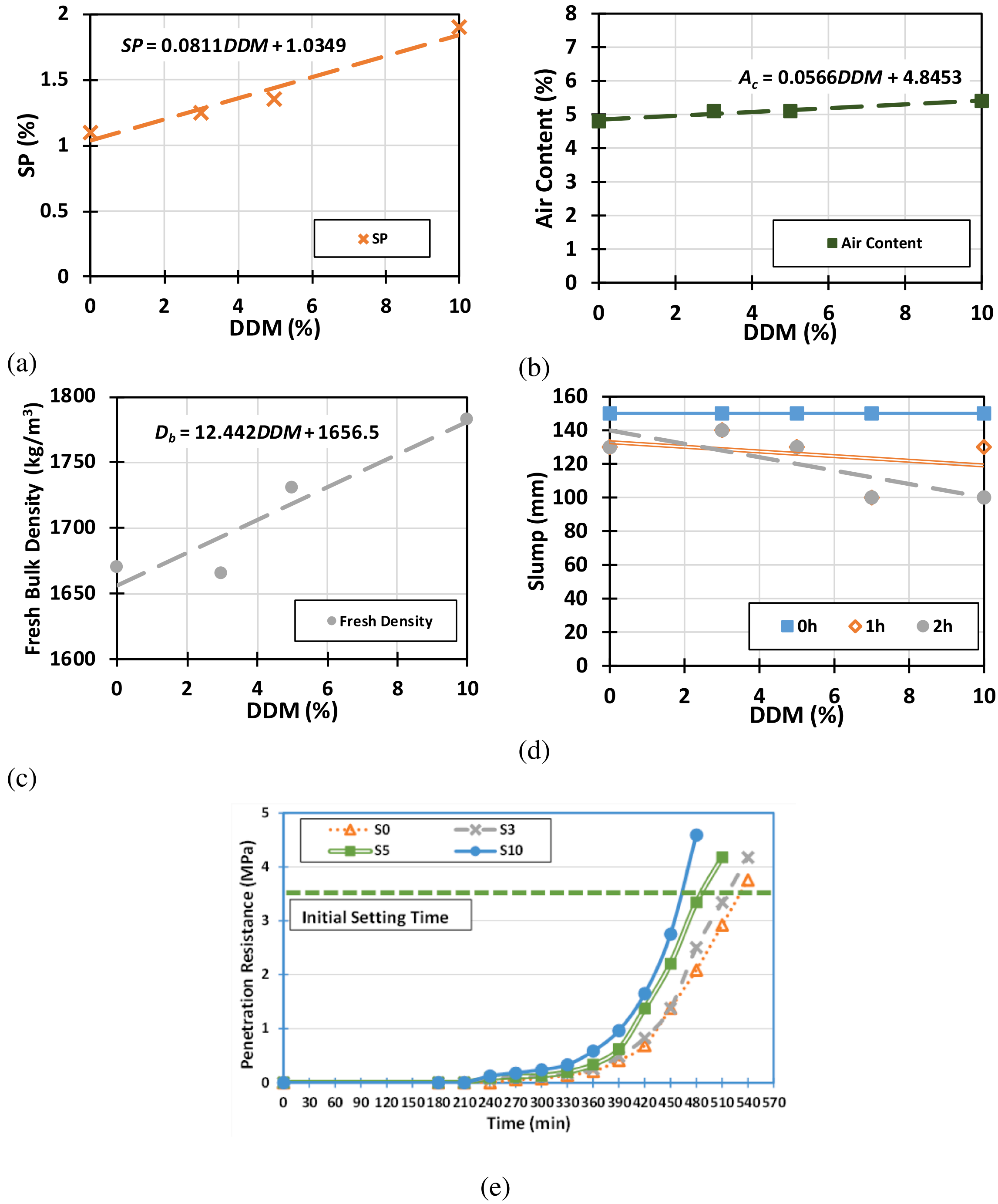



**Fig. 11.** The effect of dam dredged material replacement on fresh properties of the tested grouts: (a) Superplasticizer demand required to achieve the initial slump; (b) air content ($A_c$), (c) fresh bulk density ($D_b$), (d) slump and (e) initial setting time.

Maintaining optimal rheology is especially important in hot climates or during long transportation, where concrete behavior can change rapidly [27]. During placement, consistent rheological behavior ensures better filling of moulds and formwork, particularly in complex geometries or areas with dense reinforcement. It also improves surface finish quality and reduces the need for mechanical vibration.

Earlier research [28] documented that cement-treated dam dredged materials (DDM) with high initial water content exhibit excellent flowability and pumpability. This makes them suitable for use as controlled low-strength material in construction. However, while higher water content improves flowability, it significantly reduces compressive strength. The study emphasizes the need to balance water and cement content to achieve target strength and flow characteristics. The findings of that paper suggest the potential of DDM in backfilling and other non-structural applications [28].

The rheology of cement grouts was evaluated in this paper through stress growth tests and shear flow curve tests. The ICAR rheometer was employed to conduct the rheology tests, and the Bingham model was employed to fit the data points of the shear stress-shear rate curves to estimate dynamic yield stress and plastic viscosity. Previous studies proposed other models that can predict the rheology of cement grouts accounting for several experimental factors. A genetic expression programming (GEP) was employed by [29] to predict the rheological characteristics (shear stress and viscosity) of cement grout mixtures with stabilizers (clay, sand and lime). They developed individual equations for each stabilizer. Equations were proposed by [30] using genetic algorithm to predict the rheological behaviour of superplasticized cement paste considering the following experimental factors: ambient temperature, mixing time and superplasticizer dosage. The following superplasticizers were used: polycarboxylate based admixture, melamine based admixture and naphthalene sulphonate based admixture. They proposed an individual equation for each superplasticizer. Güllü [31] employed gene expression programming to predict the rheological behaviour of grout bottom ash to be used for jet grouting columns. The current authors are planning to conduct future research employing an artificial neural network (ANN) technique to develop a predictive model for the rheological performance of cement grout mixtures. The model will consider DDM content as a key parameter.

#### 4.2.2. *Stress growth*

Stress growth curves illustrating the development of torque at rest (low shear rate) over the first 60 s are presented in Fig. 12. It can be observed that the torque at rest increased linearly in the first few seconds. At a certain torque (threshold), the stress growth curve becomes almost a plateau over the remaining time. This threshold torque corresponds to static yield stress; which is the shear stress required to initiate the flow. Figs. 12a-c reveal that the peak torque is higher when the content of dam dredged material is greater. Thus, a greater shear stress is required to initiate the flow for cement grout with a higher DDM content. Furthermore, the peak torque is greater when the elapsed time is higher. This was expected, as the mix becomes stiffer over time, requiring a higher torque to initiate the flow of the grout.

#### 4.2.3. *Thixotropy*

The equilibrium yield stress was calculated using the average of the last 10 s torque at rest (stress growth curve) for each mixing time (0 s, 3600 s, 7200 s). The data points were fitted to linear function as shown in Fig. 13a. The slope of each line in Fig. 13a describes the evolution of the thixotropy of the cement grouts over time [32], and it indicates the rate of the grout structure build-up or flocculation [33]. The curves for all cement grouts in Fig. 13a had slopes <0.1, indicating weak thixotropy [34]. It should be noted that the viscosity of a fluid having thixotropic behaviour increases with a higher shear stress.

To understand further the thixotropic behaviour of the grout mixes, the thixotropy index was calculated by dividing the static yield stress over the dynamic yield stress, and the results are displayed in Fig. 13b The thixotropy index compares the yield stress at a lower shear rate with a higher shear rate [33]. The thixotropy index of a fluid is a valuable parameter and can be used to evaluate its thixotropy. The thixotropy index for all tested cement grouts is relatively low (<2), indicating that the studied grout mixes have weak thixotropy behaviour [35], which is consistent with the earlier observation. Moreover, cement grout with a higher content of dam dredged materials, had a lower thixotropy index and thus weaker thixotropic behaviour (Fig. 13b). Similarly, the cement grout at a higher elapsed time exhibits a lower thixotropic nature. Thus, the more content of DDM, the cement grout becomes more viscous with

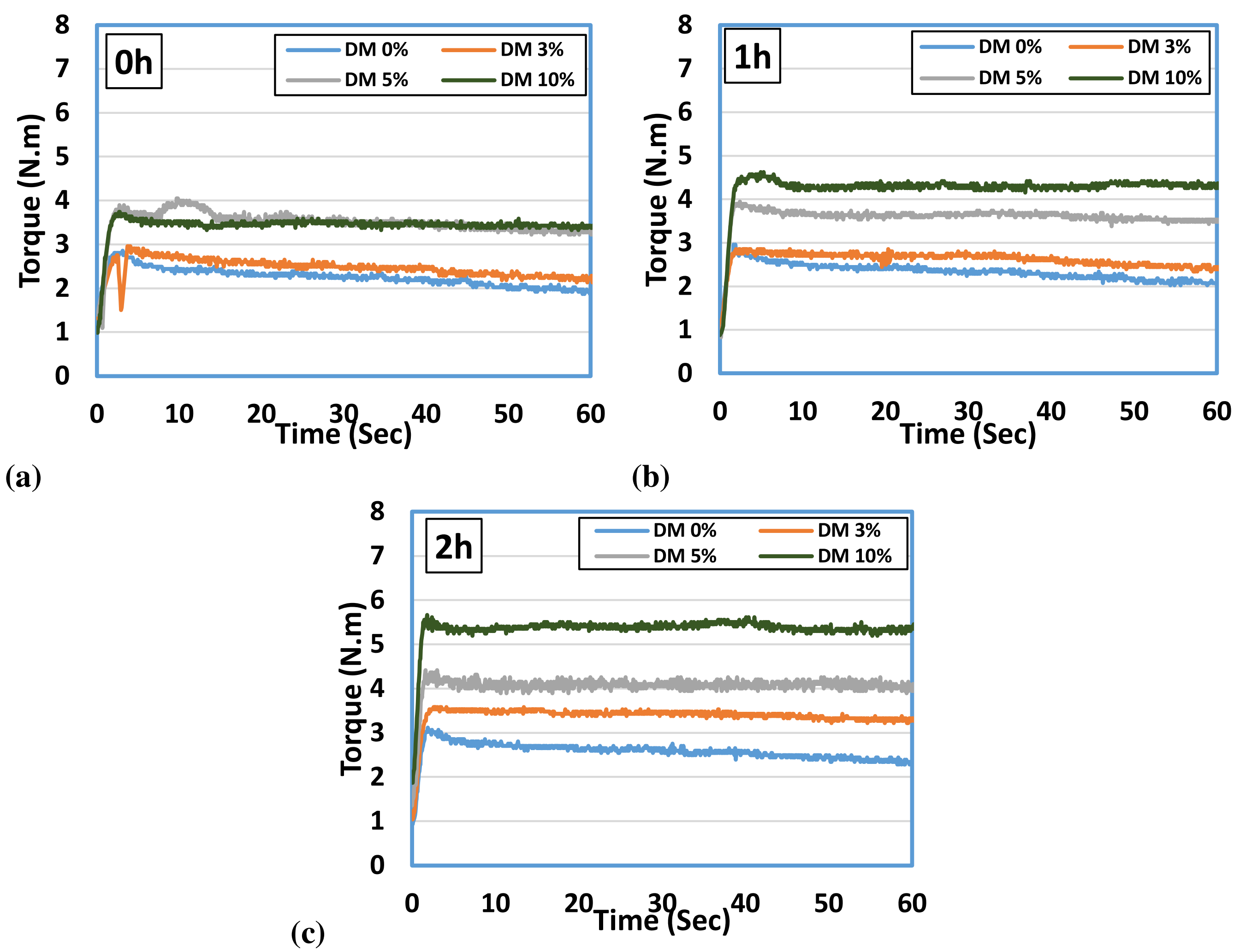



**Fig. 12.** Stress growth results: (a) immediately after mixing, (b) after one hour of mixing and (c) after 2 hrs of mixing.

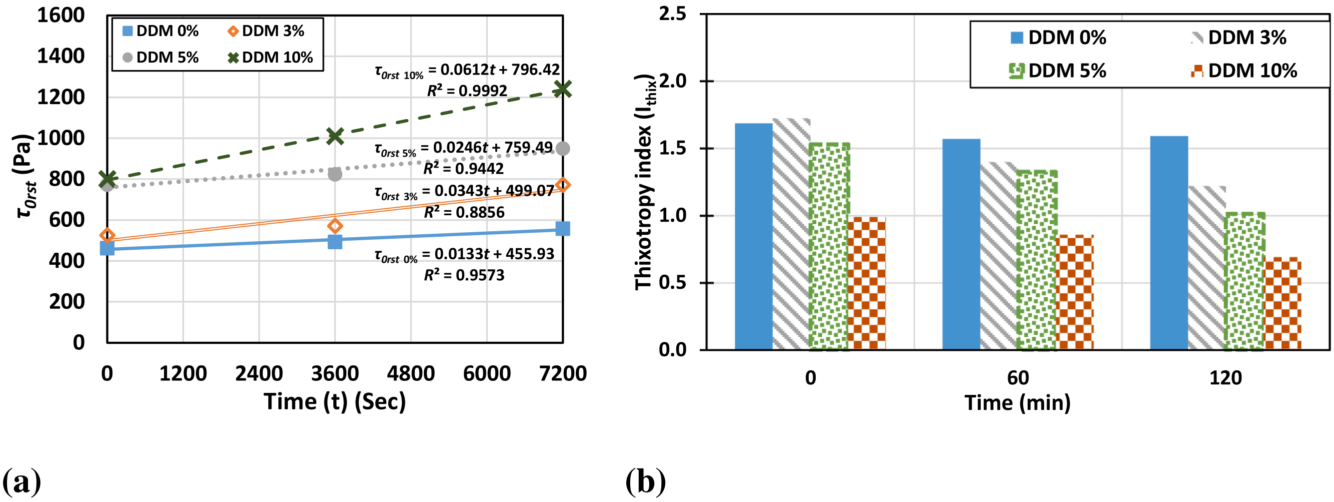



**Fig. 13.** Thixotropy evaluation of the cement grout mixes: (a) equilibrium yield stress at rest ($\tau_{0rst}$) and (b) thixotropy index ($I_{thix}$).

time at standstill conditions.

*4.2.4. Modulus of rigidity*

The data points of the stress growth curves during the first two seconds (very low torque) were plotted versus time in Fig. 14, and fitted to linear trends. The slope of each curve indicates how rigid the fresh cement grout mix is at low torque/strain [36]. This reveals useful information about the rheological behaviour of the grouts at low shear stress/strain. At low shear strain, the microstructure of cement grouts is undisturbed, and the particles of the cement grouts are close to each

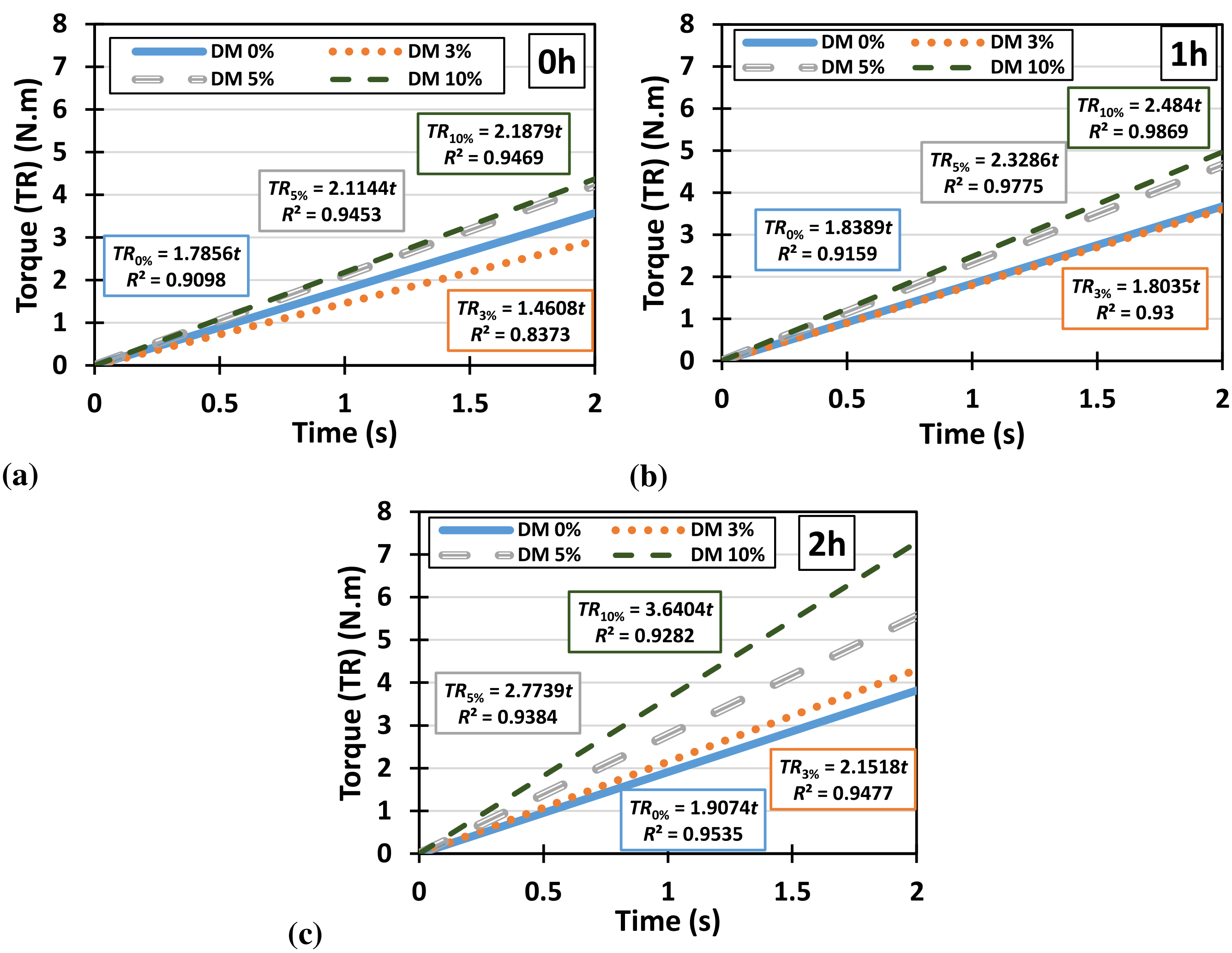



**Fig. 14.** Rigidity evaluation of the cement grout mixes incorporating dam dredged materials (DDM): (a) at 0 min, (b) at 60 min and (c) at 120 min.

other [37]. When the stress is removed, the structure can recover elastically. However, when a critical shear stress is exceeded (denoted as static yield stress), the cement grouts will shift from elastic to viscous status [37]. Fig. 14a shows the results at 0 time (initial), Fig. 14b shows the results at 60 min and Fig. 14c shows the results after 120 min. The slope of the curve increased with a higher content of dam dredged materials, indicating that the incorporation of the dam dredged materials enhanced the rigidity of the mixes thus, the mix becomes more stable at rest [38]. Further, the slope of the mixes progressively increased with elapsed time, suggesting that the grout mixes become more rigid at higher times. This is expected, as the mix becomes stiffer over time due to cement hydration and water evaporation, causing the cement particles to come closer together and increasing the modulus of rigidity.

#### 4.2.5. *Shear flow curves*

The shear flow curves were plotted in Fig. 15 for all mixes studied in this investigation. Fig. 15a displays the shear flow curves immediately after mixing (0-time), and Figs 11b and c present shear flow curves of the grout mixes after 60 min and 120 min, respectively.

The Bingham model that fits the data points of the shear flow curves was used to obtain the dynamic yield stress and plastic viscosity. The dynamic yield stress is the intercept of the Bingham line with Y-axis and plastic viscosity is the slope of that line. The dynamic yield stress is the stress required to maintain the flow, while the plastic viscosity is the resistance to flow [39].

Fig. 15 shows that the measured torque increased with a higher content of the dam dredged materials over the range of rotational speed. Slight shear thickening behaviour was observed for grout mixes incorporating high content of dam dredged materials (i.e., 10 %), as the flow curves were slightly concaved up (Pan et al., 2015). The thixotropic behaviour of the grouts creates a cohesive matrix during flow, enhancing its stability and preventing particle segregation [27]. Shear thinning fluids experience interparticle interaction while flowing. The suspended particles in such fluids agglomerate creat clusters causing structure jamming, which increases resistance to flow at higher shear rates [39]. It can be noticed from Fig. 15 that the torque over the shear rate is greater when time elapsed, indicating that mixes become stiffer with time.

#### 4.2.6. *Static/ dynamic yield stresses and plastic viscosity*

The static yield stress values of the cement grout mixes are shown in Fig. 16a. As shown from the figure, the static yield stress increased with more content of dam dredged materials for all studied elapsed time (Fig. 16a). Thus, higher shear stress is required to initiate the flow of grout with greater content of dam dredged materials. In addition, larger shear stress is required to initiate the flow of a cement grout after a longer mixing time, as evidenced by higher static yield stress with a longer time.

Similar to static yield stress, the dynamic stress increased with higher

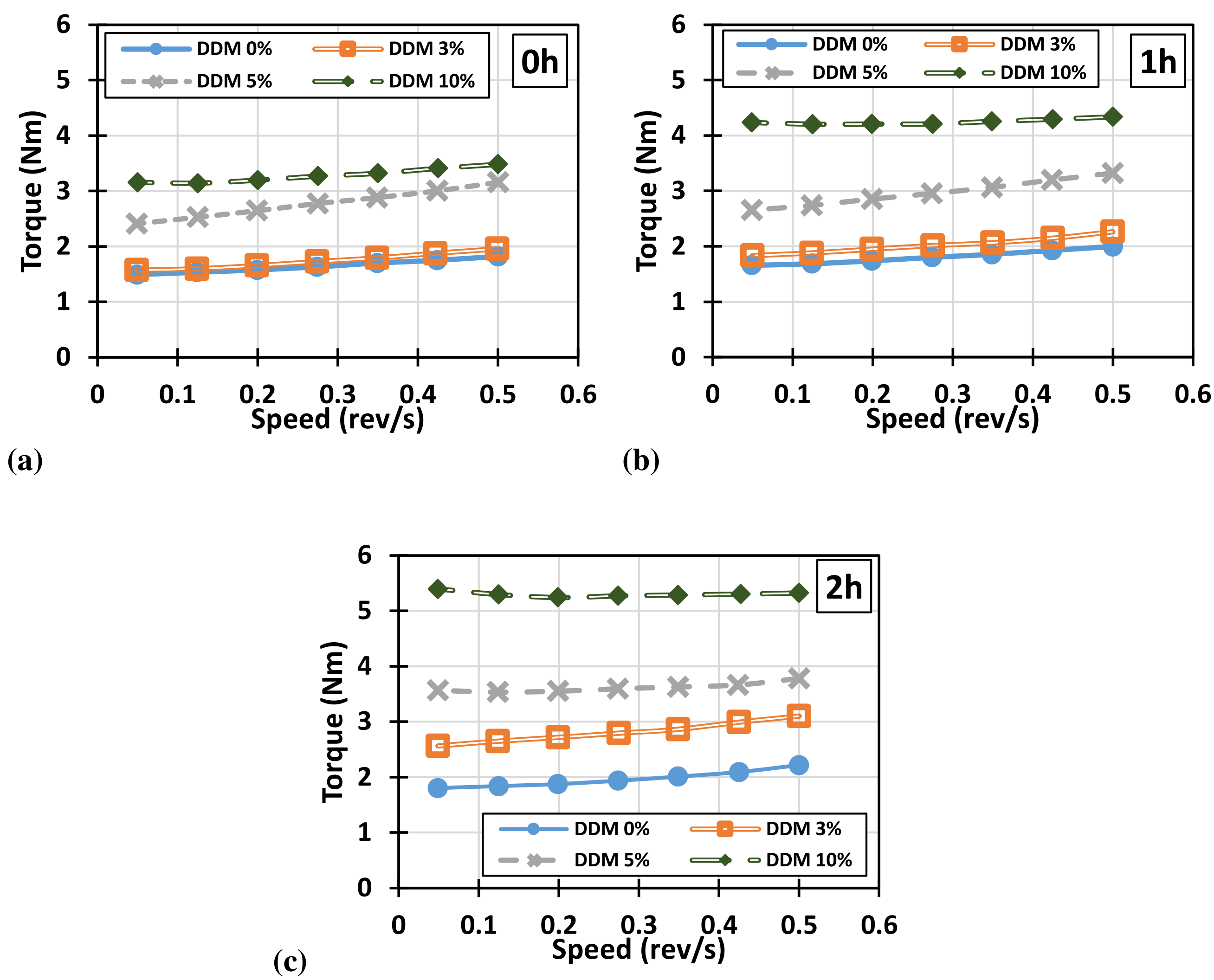



**Fig. 15.** Shear flow curves of the cement grout mixes incorporating dam dredged materials (DDM): (a) at 0 time, (b) at 60 min and (c) at 120 min.

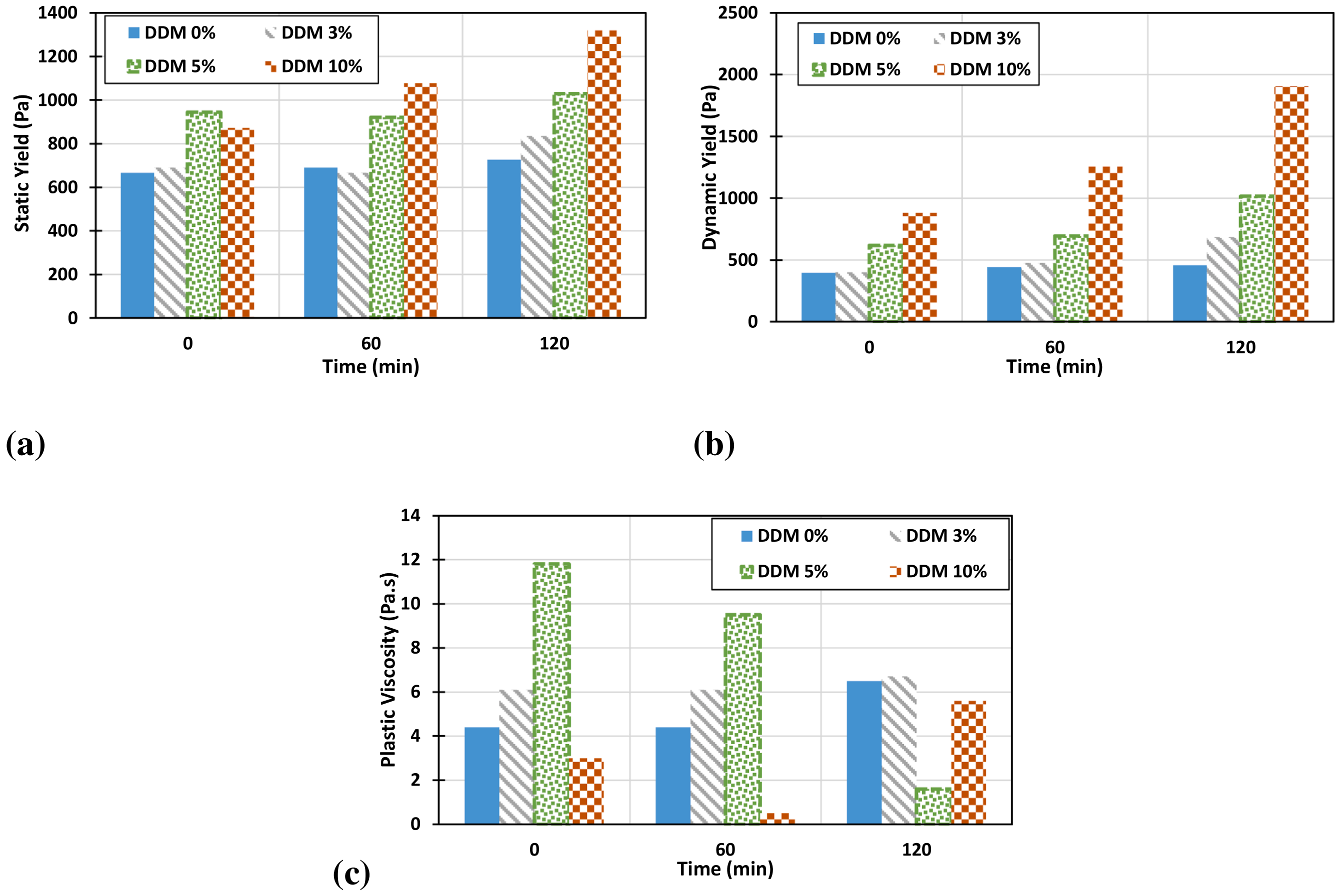



**Fig. 16.** Effect of dam dredged materials (DDM) on: (a) statics yield stress, (b) dynamic yield stress and (c) plastic viscosity of cement grout mixes investigated.

content of dam dredged material and with longer mixing time (Fig. 16b). Generally, the dynamic yield stress is lower than the static yield stress, except for the grout mix incorporating high content of dam dredged materials (10 %) at longer mixing time (60 min and 120 min). This indicates that special attention should be taken when pumping cement grouts incorporating high content of dam dredged materials.

Plastic viscosity measurements for cement grouts incorporating dam dredged materials are shown in Fig. 16c. For mixing time up to 60 min, the plastic viscosity increased with higher content of dam dredged materials for up to 5 % replacement level. However, a significant drop in plastic viscosity can be observed for cement grouts with 10 % dam dredged materials. This can be an artifact as plastic viscosity is the slope of the shear flow curves, and this mix had the highest dynamic yield stress, and thus its flow curves had low slope. Therefore, no clear conclusion for the plastic viscosity can be depicted for cement grouts at 120 min.

### *4.3. Mechanical properties and durability results*

#### *4.3.1. Mechanical properties*

The hardened density and compressive strength were measured at 7d, 28d, 56d and 90d, for all grout mixes. Figs. 17a and b show the measured data points of the hardened density and the compressive strength, respectively versus the percentage of DDM along with the error bars of possible 5 % error in the data, which corresponds to 95 % confidence interval. Fig. 17b shows also the fitted curves (lines) along with the regression equations. The hardened density increased progressively with dam dredged material content. For example, the 90d hardened density increased from 1690 to 1785 kg/m$^3$ (about 6 %) for DDM 0 % mix and DDM 10 % mix, respectively. The compressive strength also increased consistently with higher content of dam dredged materials. The increase of hardened density and compressive strength could be attributed to the fine particles of the silt that were able to fill the small voids. The observed increase in compressive strength and hardened density with higher DDM content can be attributed to microstructural densification facilitated by the fine silt-sized particles present in the DDM. These fine particles act as physical fillers, occupying voids between larger cement and aggregate particles, leading to a more compact and less porous matrix [10]. This filler effect enhances particle packing density, reduces capillary porosity, and contributes to the overall strength of the grout. Thus, it can be concluded that incorporating the dam dredged material is beneficial for the compressive strength of cement grouts. The standard deviation of the hardened density was in the range of 37.80 –48.51 kg/m$^3$, where the 56d has the lowest value, while the 90d has the highest. The standard deviation of the compressive strength was in the range of 1.46 – 2.21 MPa, where the 7d has the lowest value and the 56d has the highest.

#### *4.3.2. Durability*

The durability was evaluated indirectly from the electrical properties and directly from shrinkage of the grout mixes. The electrical conductivity and electrical resistivity of the grout mixes were measured using Merline equipment. Fig. 18a and b show the measured data points of the electrical conductivity and resistivity, respectively versus the percentage of DDM along with the error bars of possible 5 % error in the data, which corresponds to 95 % confidence interval. For 28-day curing, the electrical conductivity of the investigated grouts increased with dam dredged materials content (Fig. 18a), while electrical resistivity decreased. However, for a higher age of curing (56d and 90d), the dam dredged materials content variation did not have an impact on the measurement of electrical resistivity and electrical conductivity, and no significant changes can be depicted over the replacement levels of dam

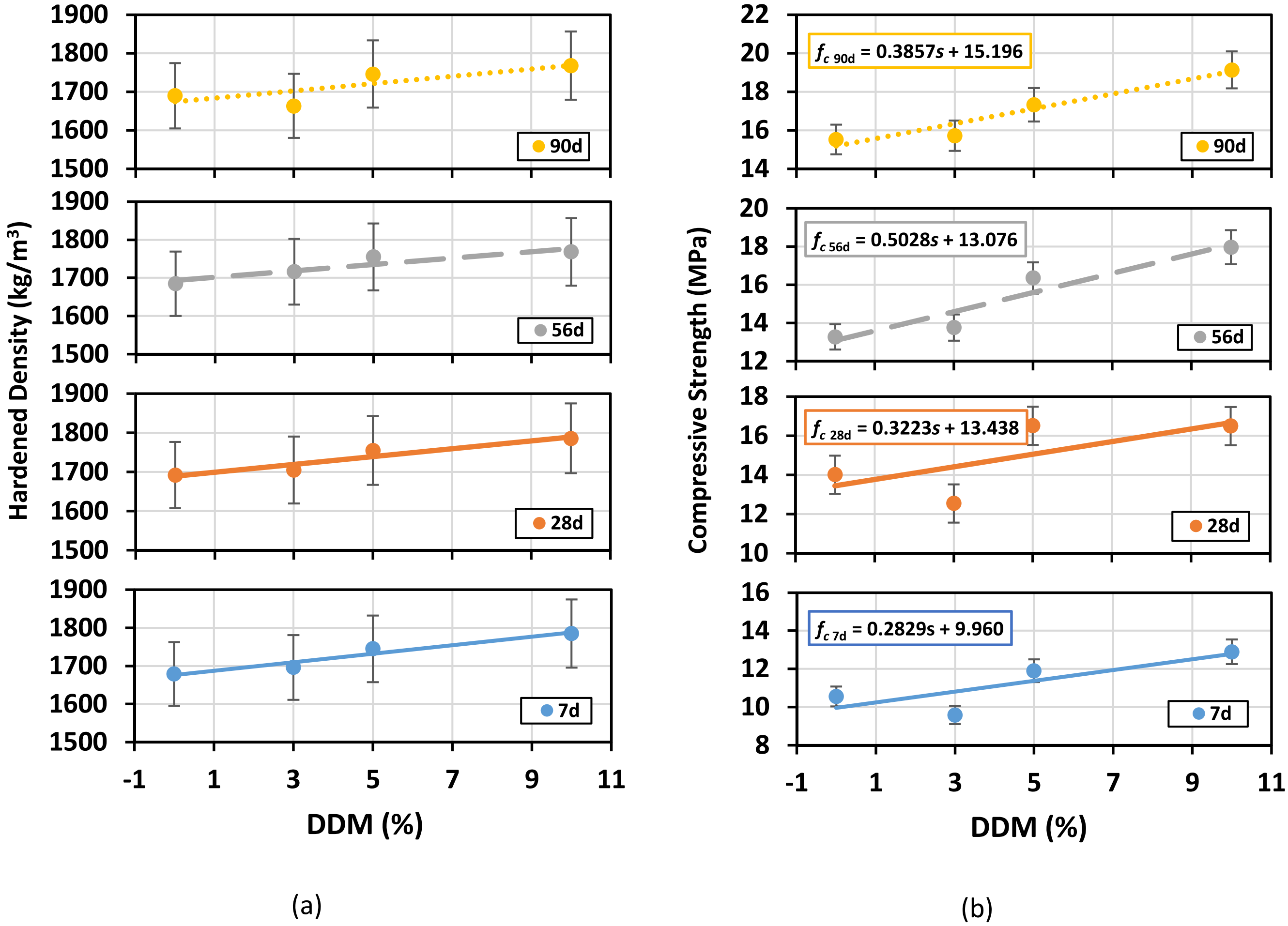



**Fig. 17.** Effect of dam dredged materials (DDM) content on: (a) hardened density and (b) compressive strength.

dredged materials. The standard deviation of the electrical conductivity was in the range of 0.54 –20.25 milli-S/m, where the 90d has the lowest value while the 7d has the highest. While the standard deviation of the electrical resistivity was in the range of 3.71–11.22 Ωm, where the 90d has the lowest value while the 7d has the highest.

The decrease of conductivity of a saturated specimen with curing age could be due to the reduction of the capillary porosity, as the pore structure refined with curing age [24]. Further, the decrease in bulk electrical conductivity and increase in resistivity with higher curing time reflects the microstructure build-up, as tested specimens get denser with time during hydration process [23]. Further, the increase of electrical conductivity of samples cured for 28d as a function of DDM content could be due to the variations in ionic concentration of the pore fluid of the hardened grout. More ionic exchange in the pore fluid takes place, when the replacement of the dam dredged materials is greater. The reason why no impact of the DDM content on the electrical conductivity and electrical resistivity of grouts cured at 56d and 90d could be attributed to that at longer hydration duration, more cement was hydrated. Accordingly, the effect of the DDM on electrical properties was diminished, as the grout becomes denser (see Fig. 18).

The electrical conductivity results were converted to rapid chloride permeability (RCP) value by dividing the measured values of electrical conductivity over the conversion coefficient specified by the manufacturer (0.00483). The converted RCP values are presented in Fig. 19. As per ASTM C1202, the data points in Fig. 19 were divided into four regions (I, II, III, and IV), based on the degree of chloride permeability. The data points that have converted RCP values <1000 coulombs are located in region I and rated very low. In Region II the converted RCP values between 1000 coulombs and 2000 coulombs and corresponding mixes are rated low. The mixes located in Region III have converted RCP values between 2000 coulombs and 4000 coulombs are rated medium. Grout mixes with converted RCP values greater than 4000 coulombs are in Region IV and rated high.

As shown in Fig. 19, all the grout mixes incorporating dam dredged materials and cured for 28d were rated high, indicating that they have high sensitivity to chloride permeability. The grout mixes cured for 56d are rated high except for the mixes incorporating 0 % and 5 % of dam dredged materials. However, a significant improvement in chloride penetration can be depicted for grout mixes after 90 days of curing, as all mixes were rated medium chloride permeability. This indicates that the dam dredged materials improved their durability after prolonged curing. Dam dredged materials contribute to durability by filling voids within the grout matrix, leading to a denser microstructure. Over prolonged curing periods, the fine particles of the silt enhance particle packing, which reduces the porosity and permeability of the grouts. This denser matrix limits the pathways for chloride ions to penetrate, resulting in lower chloride permeability. The medium chloride permeability rating for all mixes highlights the effectiveness of incorporating dam dredged materials in improving the long-term performance and durability of the grout, particularly in chloride-rich environments. The results reveal that the grout mixes cannot be used for reinforced concrete with steel, due to their permeability to chloride. However, it should be noted that the grout mixes are suitable for the proposed applications (i.e., plaster, and grout adhesion under tiles), as these applications are mortar with no reinforcement.

Fig. 20 shows the shrinkage results measured for the studied cement

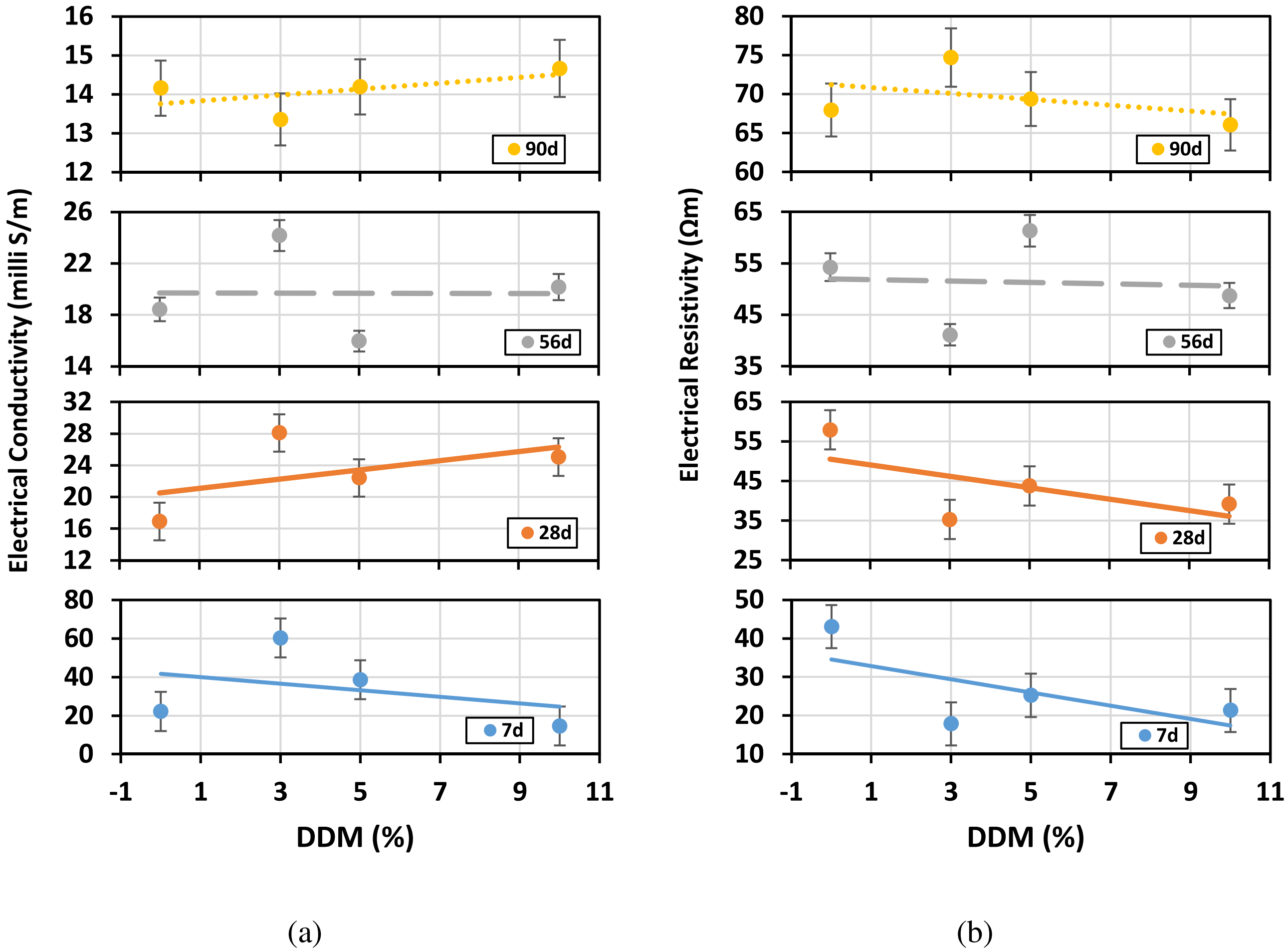



**Fig. 18.** Marline results for the studied mixes: (a) electrical conductivity and (b) electrical resistivity.

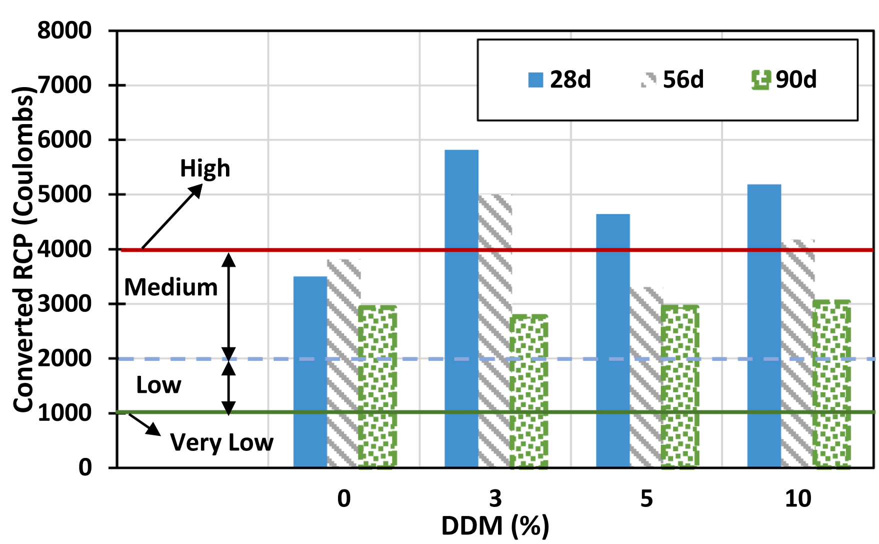



**Fig. 19.** Converted RCP values of grouts incorporated dam dredged materials.

grout incorporating dam dredged materials. The grout mix with no dam dredged materials is referred to as the reference mix. The grout mixes with 3 % and 5 % dam dredged materials experienced shrinkage higher than the reference mix, while the one with 10 % dam dredged materials had lower values than the reference mix (with no dam dredged materials). The highest shrinkage is for the mix with 3 % dam dredged materials replacement level. It seems that with a higher content of dam dredged materials, shrinkage decreased and reached negative values (expansion) for the grout with 10 % dam dredged materials replacement level. This could be attributed to that when silt is introduced to grout, it tends to retain water owing to its high surface area due to the capillary action [25]. Thus, the cement grouts with limited dam dredged

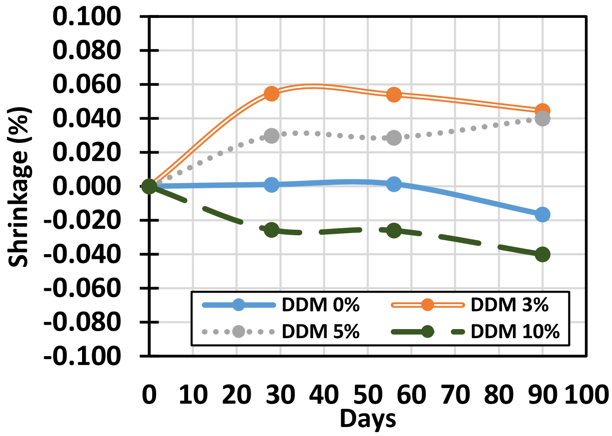



**Fig. 20.** Shrinkage results for the cement grout with dam dredged materials (DDM).

materials replacement level (3 %) experienced some shrinkage (0.06 %), due to insufficient water retention leading to volume reduction during curing. Conversely, the mix with 10 % dam dredged materials replacement level had little expansion (0.04 %), because the increased silt level retains more water. This can promote hydration and voids filling, leading a slight net increase in volume.

### *4.4. Pilot study*

The experimental results presented in Stage 3 and the physical and chemical characterizations of dam dredged materials presented in Stage 1 showed that dam dredged materials have a high potential to be considered for tile adhesion and plaster applications. The developed mixes can pose smooth finishing and have adequate strength properties, which are important factors in tile adhesion and plaster grouts. The developed dam dredging materials mixes were used under actual tiles, as an adhesion layer, and on the surface of a block, represents a plaster layer. This is to verify the potential of utilizing these materials in these construction applications (floor tilling and wall plastering). Fig. 21a shows photos of a tile adhesion sample at 0 time (fresh), and Fig. 21b shows the same tile adhesion after 11 month that was exposed to the harsh environments during this period (temperature exceeds 45 °C in summer). No cracks can be observed due to environmental effects (Fig. 21b).

Figs. 21 (c and d) show plaster application samples (fresh and after 11 months), it can be observed that plaster incorporating the dam dredged materials produced smooth finishing plaster with no cracks after 11 months. It can be concluded that grout prepared with the dam dredged material is suitable to be used for tile adhesion and plaster applications. However, further investigation should be carried out to optimize the mixes.

## 5. Conclusions

The use of Dam Dredged Material (DDM) in construction is a scalable and economically practical approach, particularly in regions with regular dredging operations that generate large volumes of material. Its fine particle size enables it to act as a filler, reducing the need for natural aggregates and lowering material and disposal costs. However, widespread adoption faces challenges such as variability in material quality and lack of standards and industry acceptance. Addressing these issues through the development of construction standards is essential for enabling the broader use of DDM in sustainable construction practices.

The study explores a sustainable approach to construction by

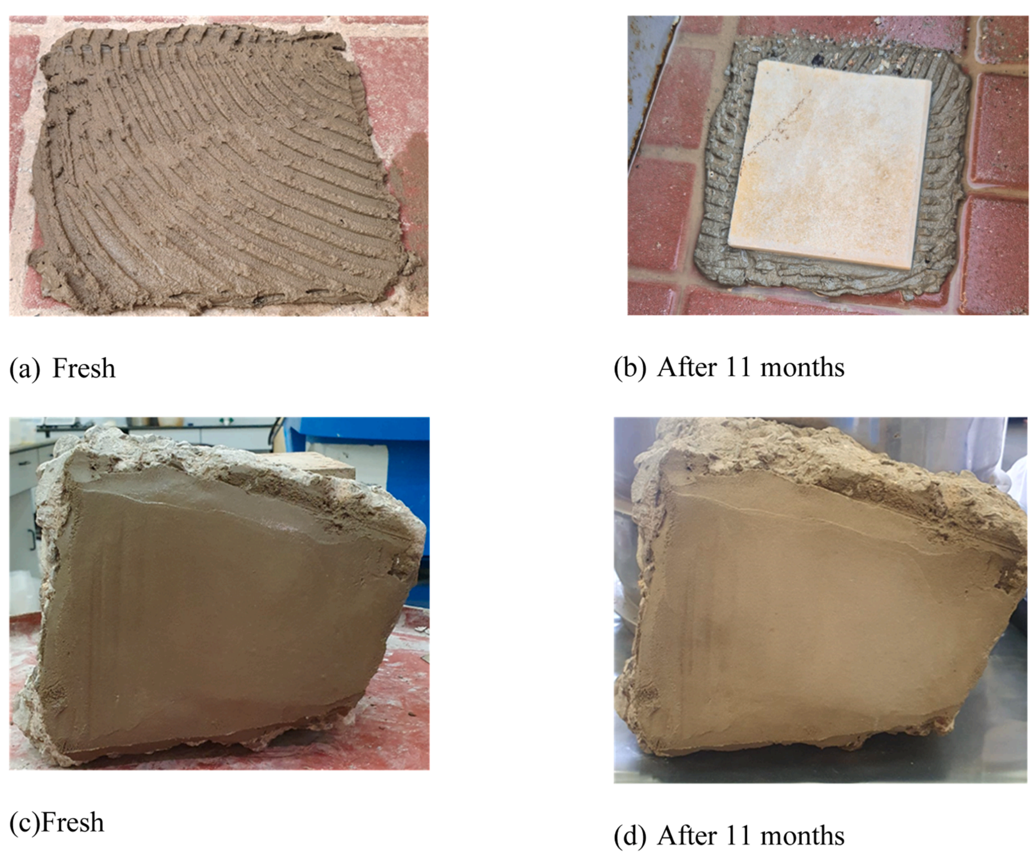



**Fig. 21.** Applications as tile adhesion and plater using the grout mixes developed: grout adhesion under tiles (a) fresh and (b) after 11 months, plaster: (c) fresh and (d) after 11 months.

examining how dredged materials from UAE dams might serve as replacement for traditional fine aggregates in cement grout. The research aims to evaluate if these dredged materials could be used as grout plaster and tile adhesion in construction, thus minimizing the dependence on conventional resources. The outcomes of the current research are expected to promote resource efficiency and reduce environmental impacts. The goals of this study align with the UAE's strategic vision for sustainable development and supporting the transition toward more sustainable construction practices in the region. The study presents detailed experimental work investigating the fresh, rheology, mechanical, and durability properties of the developed grouts. Several key conclusions can be drawn from the paper:

1. The physical and chemical analysis revealed that the dam dredged materials pose a low plasticity index, low water-soluble content and low organic content, indicating that these materials have the potential to be used in construction applications.
2. The required superplasticizer for the gout mixes to achieve the target initial slump, increased progressively with the replacement level of dam dredged materials.
3. The air content of grout mixes increased slightly with more content of dam dredged materials.
4. The bulk fresh density of the dam dredged materials increased with higher content of dam dredged materials dredged materials.
5. The incorporation of dam dredged materials did not have a negative impact on slump for up to 1 hour however, the slump of grout decreased consistently with dam dredged materials content after 2 h. Thus, special care should be taken for prolonged mixing when these materials are incorporated.
6. The initial setting of grout mixes shortened with a higher replacement level of dam dredged materials.
7. Weak thixotropy was observed for all grout mixes however, the grout mixes experienced lower thixotropic behaviour when the content of dam dredged materials is higher.
8. Grout mixes with higher content of dam dredged materials had higher modulus of rigidity.
9. Slight shear thickening behaviour was observed, for grout mixes with higher content of dam dredged materials.
10. Static yield stress and dynamic stress increased with higher content of dam dredged material and with longer mixing time.
11. Dam dredged material was found to be beneficial for both hardened density and compressive strength at all ages (7d, 28d, 56d, 90d), as both properties increased with higher replacement levels of these materials.
12. High replacement of dam dredged materials, offset the shrinkage of grout. due to the silt capillary action.
13. The electrical conductivity of grout specimens cured at 28d increased with the content of dam dredged materials, while the resistivity decreased. However, for longer curing time (56d and 90d), both conductivity and resistivity were not sensitive to changes with dam dredged materials content.
14. Cement grouts with dam dredged materials and cured for 90 day had a converted RCP values below 3000 Coulombs (medium), indicating their good durability and suitability to be used for plaster and grout tilling applications.
15. The prepared tiling and plastering grouts showed satisfactory performance over 11 months, and no noticeable cracks or shrinkage were observed. This indicates that the dam dredged material has the potential to be used in plastering and tiling applications, which can promote sustainability in construction. However, a more comprehensive experimental program is required to set fundamental guidelines and recommendations for the use of these materials in construction sectors under UAE environmental conditions.

## CRediT authorship contribution statement

**Samer Al Martini:** Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Reem Sabouni:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Mohamed Elhakeem:** Writing – review & editing, Funding acquisition, Formal analysis. **Mahmoud Masri:** Visualization, Investigation.

## Declaration of competing 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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## Data availability

Data will be made available on request.

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