Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 335-342, 9, 2024
© Telif hakkı IJANSER'e aittir
Araştırma Makalesi

IJANSER

https://as-proceeding.com/index.php/ijanser
ISSN:2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 335-342, 9, 2024
Copyright © 2024 IJANSER
Research Article

Mechanical Strength and Drying Shrinkage of Self-Compacting Concrete having Mine Tailings and GGBS

Shahir Ahmad Safi*[1], Khaled Waleed Radman [1] and Ali Raza [1]

[1] *Department of Civil Engineering, University of Engineering and Technology Taxila, 47050*

**(shahirahmad229@gmail.com)*

(Received: 18 October 2024, Accepted: 27 October 2024)

(4th International Conference on Engineering, Natural and Social Sciences ICENSOS 2024, 22-23 October 2024)

ATIF/REFERENCE: Safi, S. A., Radman, K. W., & Raza, A. (2024). Mechanical Strength and Drying Shrinkage of Self-Compacting Concrete having Mine Tailings and GGBS, *International Journal of Advanced Natural Sciences and Engineering Researches*, 8(9), 335-342.

Abstract – To address land occupation and environmental pollution from mine tailings (MTL) accumulation, MTL has been used as a replacement for cement or fine aggregate in concrete production. This study focused on producing self-compacting concrete (SCC) by substituting MTL for an equal mass of GGBS, offering a sustainable way to incorporate MTL into SCC. The research investigated the effects of replacing GGBS with MTL on both the fresh and hardened properties of SCC, evaluating parameters such as slump value, drying shrinkage, compressive strength (CS), and split tensile strength. Results showed that adding MTL impacted workability and performance. While 50% MTL reduced workability initially, it still met standard requirements. Early drying shrinkage increased with higher MTL content but remained manageable at 25% substitution. Compressive strength improved significantly at one, three, and seven days with MTL, stabilizing at 28 days with a 2.86% increase in CS.

Keywords – Self-compacting concrete, recycled aggregates, compressive strength, split tensile strength

I. INTRODUCTION

The mining sector generates substantial quantities of mixed waste, with tailings representing the leftover material following ore processing. Self-compacting concrete (SCC) is a modern material designed to flow under its own weight, allowing it to fill formwork and steel reinforcements without needing vibration, while maintaining high levels of fluidity and stability [1]. Despite containing the same fundamental ingredients—cement, water, aggregates, admixtures, and mineral additives—the workability of SCC differs significantly from that of conventional concrete (NC). The increased inclusion of mineral additives in SCC accounts for its superior workability [2, 3]. Ground granulated blast furnace slag (GGBS) is often incorporated into SCC due to its particle structure and pozzolanic properties [4, 5]. The use of GGBS in adequate proportions has been shown to ensure the necessary fluidity and stability of SCC [6, 7]. However, in certain regions of China, recent environmental regulations targeting pollution from coal-fired plants and introducing carbon taxes have reduced the availability of high-quality GGBS, leading to a steep increase in its price.

Supplementary cementitious materials play a crucial role in altering the fresh and hardened properties of SCC. However, the use of mine tailings (MTL) as a mineral additive in SCC remains unexplored. Therefore, the objective of this study is to examine how substituting GGBS with MTL affects the fresh and hardened properties and the microstructure of SCC. The analysis will cover slump value, drying shrinkage, compressive strength (CS), and split tensile strength (STS). The research highlights that using MTL as a replacement for GGBS in SCC offers considerable environmental benefits. By incorporating industrial waste, the approach helps address the issue of molybdenum mining residues, enhances concrete performance and durability, and fosters sustainability. The environmental footprint of concrete production can be reduced by substituting MTL, which lowers carbon emissions and reduces the need for cement. This innovative use of waste materials also promotes the development of cost-effective and environmentally sustainable construction methods, advancing the field of green building practices.

II. EXPERIMENTAL PROGRAM

i. Materials

Ordinary Portland cement with a surface area of 365 m²/kg was utilized. The physical properties of GGBS and MTL, used as fillers, are provided in Table 1. The apparent densities of GGBS and MTL were 2550 kg/m³ and 2890 kg/m³, while their specific surface areas were 987 m²/kg and 451 m²/kg, respectively. RCA was sourced from crushed concrete cylinders, one year old, with compressive strengths ranging from 25 MPa to 35 MPa. The apparent densities of sand and RCA were 2598 kg/m³ and 2786 kg/m³, and their bulk densities were 1379 kg/m³ and 1719 kg/m³, respectively. The admixture used in this study consisted of two chemical additives (a water reducer and a retarder) in a mass proportion of 4:6. During the entire trial, regular tap water was combined with a water reducer containing 20% solids.

.

Table 1. Basic characters of filler materials.

Physical property	**Filler materials**	
	GGBS	**MTL**
Soundness	Qualified	Qualified
Apparent density	2550 kg/m³	2890 kg/m³
45-micron sieve pass rate	10.7%	65.2%
Specific surface area	987 m²/kg	451 m²/kg
Moisture	0.4	0.3

ii. Testing of Specimens

The SCC mix proportions were derived through a process that began with trials of paste, followed by mortar, and finally the SCC itself. The cement content was initially determined using the design strength grade of the SCC. For the paste trial, variables like the water-to-powder ratio, admixture dosage, and type of admixture were selected. The mortar mix proportions were then adjusted continuously until the paste achieved the desired workability. In this stage, sand content was kept constant, while the admixture dosage and water-to-powder ratio were modified to ensure that the mortar met workability standards. The results from the mortar tests were used to establish the proportions for the SCC phase. Further adjustments to the sand and RCA content were made based on sieve analysis results. This approach was used to set the control mix proportions for this study. Five different replacement levels of GGBS with MTL were tested: 0%, 25%, 50%, 75%, and 100%, where MTL replaced an equivalent mass of GGBS. The SCC mix without MTL was termed Group Zero (SCC0). For each SCC mixture, the water-to-binder ratio (w/b = 0.39) and admixture dosage remained constant. The mixes SCC0, MTLS25, MTLS50, MTLS75, and MTLS100 were prepared.

The prescribed mixing sequence involved adding RCA, sand, and mineral components (cement, MTL, GGBS) to the mixer. A dry mix was performed for 30 seconds, followed by the addition of 80% of the water, and mixing for 60 seconds. The remaining water and additives were then added, and the mixture was mixed for another 180 seconds. The SCC mixes were poured into molds for curing, with workability and DS tests performed afterward. To prevent aggregate settlement, a final mixing was done before molding. After 24 hours at 20°C and 95% humidity, the samples were demolded and cured for 28 days under the same conditions.

The flowability (SF, T500, JF, VF) and air content were evaluated using the slump flow test for deformability, T500 for viscosity, V-funnel for flow capacity, and the J-ring test for passing ability. Early drying shrinkage (DS) was recorded using a non-contact device over 72 hours. Compressive strength (CS) and splitting tensile strength (STS) were tested over a period of 28 days using 100 mm cubic samples in a 2000 kN capacity compression testing machine.

III. RESULTS AND DISCUSSION

i. Slump Value

The fresh properties of SCC with different MTL contents are presented in Table 2, including parameters such as filling capacity (assessed by SF), viscosity (determined by T500 and VF), and passing ability (measured through JF and SF-JF). These characteristics are compared with standard limits and relevant literature sources [8]. The results indicate that MTL significantly affects the fresh properties of SCC. The slump values for SCC0, MTLS25, MTLS50, MTLS75, and MTLS100 were 664.45 mm, 649.90 mm, 625.65 mm, 582.00 mm, and 548.05 mm, respectively, as measured by the spread test, and 640.20 mm, 622.74 mm, 594.61 mm, 547.08 mm, and 504.40 mm, respectively, via the J-ring flow test. The SCC mixtures labeled SCC0, MTLS25, MTLS50, MTLS75, and MTLS100 were prepared accordingly.

Table 2. Results of fresh features of SCC mixes

Mix label	Slump spread test		V-funnel test	J-ring flow test		Air fraction (%)
	SF (mm)	T500 (s)	(s)	JF (mm)	SF-JF (mm)	
SCC0	664.45	5.43	10.48	640.20	24.25	3.40
MTLS25	649.90	6.21	11.25	622.74	27.16	3.49
MTLS50	625.65	6.69	21.63	594.61	31.04	3.01
MTLS75	582.00	8.15	41.90	547.08	34.92	2.52
MTLS100	548.05	9.51	46.85	504.40	43.65	2.13
Limitation	550-850	3-70	7-25	>=SF-50	0-50	-

Figure 1 illustrates the workability of fresh SCC with varying MTL substitution levels. As the MTL percentage increased, there was a noticeable decrease in workability, with a substantial 16.86% reduction at full (100%) MTL substitution. This trend aligns with previous studies [9], indicating that MTL addition negatively affected SCC's filling and flow capabilities. The reduction in workability is attributed to MTL's angular, coarse particles and the combined influence of GGBS and MTL micro-powders in the mix. These factors increased the mix's specific surface area and water absorption, resulting in lower workability [10]. Similarly, Quan et al. [11] reported a decrease in slump as MTL content increased. However, the MTLS25 mix achieved a slump flow (SF2) within the 650–800 mm range, suitable for standard construction applications such as walls and columns.

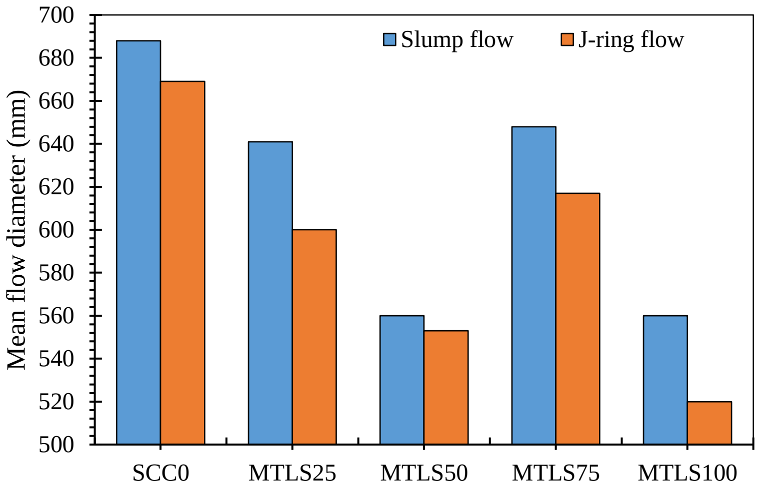

Figure 1. The SF and JF of fresh SCC with various substitution ratios of MTL.

T500 and VF, which are parameters used to assess the viscosity of fresh concrete, play a key role in determining the flowability of [SCC]. As shown in Table 2, the T500 values for the fresh [SCC] samples in this study ranged from 5.59 to 9.79 seconds. A higher substitution of MTL corresponded to an increase in [T500]. This is due to the coarse and angular shape of MTL particles, which raises viscosity by increasing inter-particle friction and resistance, thus requiring more water for proper mixing. Figure 2 demonstrates a strong linear relationship between T500 and [SF], with a high correlation ($R^2 = 0.9483$) between the two parameters.

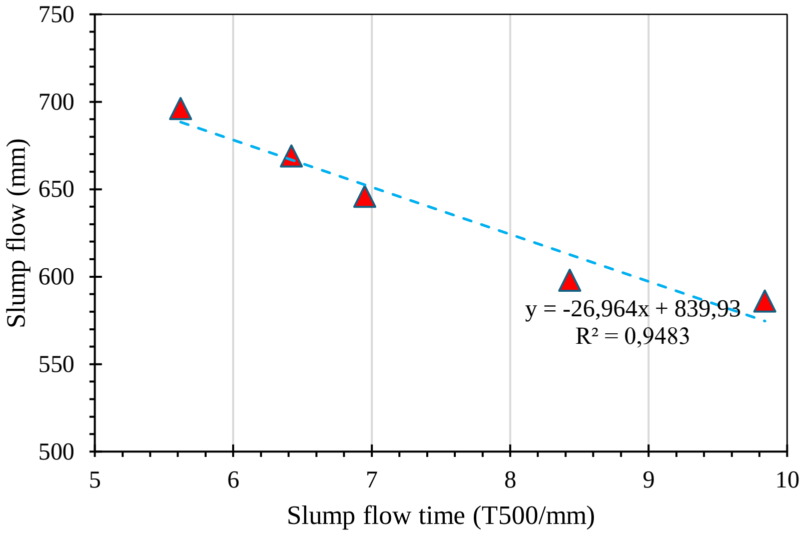

Figure 2. The correlation between SF and T500.

ii. Compressive Strength

As displayed in [Figure 3], the [CS] of [MTLS] was analyzed at different curing periods to observe strength development. Comparing the [Zcu] values across all samples, it was noted that before 3 days, those containing [MTL] exhibited a faster strength gain than [SCC0]. Specifically, after 3 days, the [CS] of [MTLS] samples increased by 32.96%, 24.27%, 15.89%, and 12.86% compared to [SCC0], indicating that [MTL] positively influenced the early-age strength of [SCC]. At one day, there was no significant link between [CS] and [MTL] content; however, after three days, [CS] tended to decrease progressively with higher percentages of [MTL] substitution. By 7 and 14 days, all samples had achieved roughly 75% and 85% of the 28-day strength, respectively. The strength increase in [SCC0] during these periods was considerably higher than that of [MTLS], likely due to [MTL]'s lower hydration activity compared to

[GGBS]. As a key cementitious material, [GGBS] plays a critical role in strength enhancement through its hydration byproducts and pozzolanic reaction. [SCC0] achieved a peak [Vmax] of 32.72 MPa at 14 days.

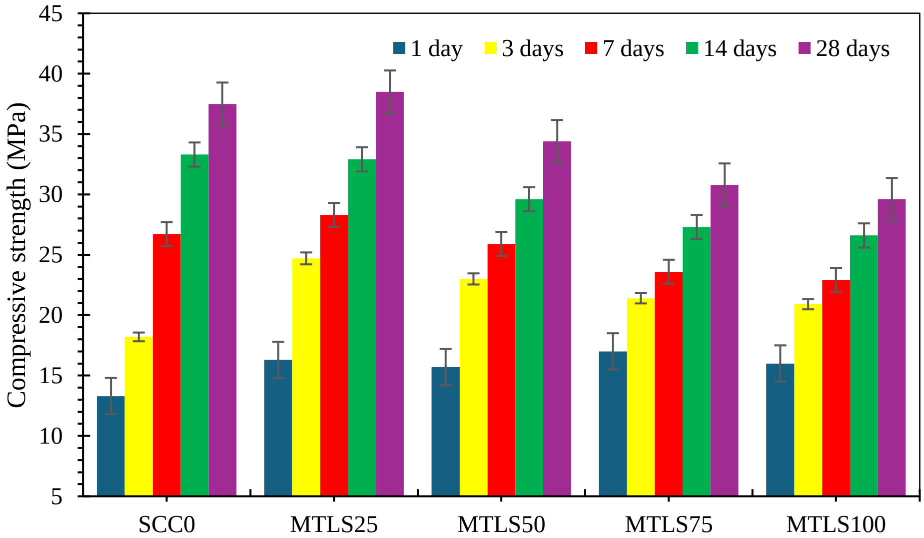

Figure 3. The CS of SCC with various substitution ratio of MTL.

After 28 days, the compressive strength (CS) of MTLS25 reached 38.5 MPa, slightly surpassing that of SCC0. In the composite cementitious powder system, substituting MTL at an optimal rate of 25% results in a more balanced particle size distribution. The pore structure analysis in Section 3.5.2 indicates that this contributes to a denser concrete matrix with fewer voids [14]. For MTLS50, the CS decreased by just 7.5% compared to SCC0, which remains acceptable for lower-strength applications. However, when MTL substitution increased to 75% and 100%, reductions in fci of 17.19% and 23.07%, respectively, were observed. This is attributed to the larger particle size of MTL compared to GGBS, which negatively affects microstructural density at higher substitution levels.

iii. Splitting Tensile Strength

The effect of MTL substitution on the 28-day splitting tensile strength (DTC) of SCC is shown in Figure 4. Like CS, this trend also shows that STS increases with MTL replacement at first, but subsequently decreases as the level of substitution increases. Of all the fractions examined, MTLS25 attains the maximum STS of 2.65 MPa.

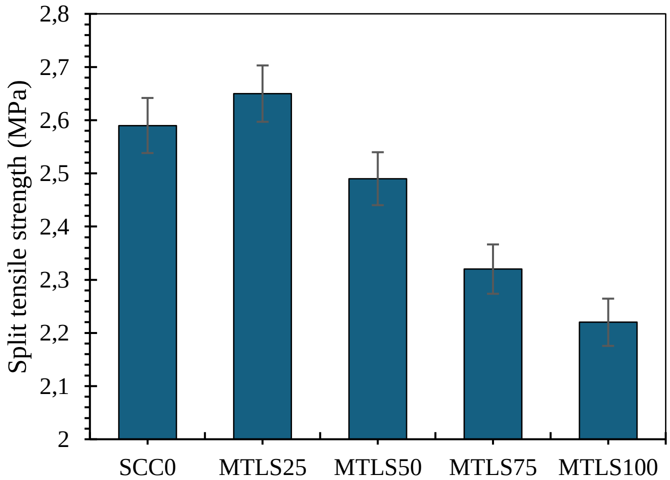

Figure 4. The STS of SCC with various substitution ratio of MTL.

Based on the literature [15], the correlation between CS and STS of the concrete can be written as $f_{sts} = af_{cu}^{b}$; where a and b are constants. With a good connection (R^2 = 0.9613), Figure 5 shows the link between CS and STS at 28 days. However, other variables like the amount of paste and powder content also have an impact on STS [8]. In comparison to SCC0, the STS values decrease by 3.79%, 11.11%, and 15.02%, respectively, when the fraction of MTL substitution surpasses 25%. The features of SCC's DS could be the cause of this decrease. Because of the unique characteristics of the tailings processing, adding too much MTL enhances the dust content, which elevates the DS of SCC. The growth of STS is negatively impacted by the ensuing shrinkage strain, which causes many microcracks at the interface between the aggregate and hydration products [16].

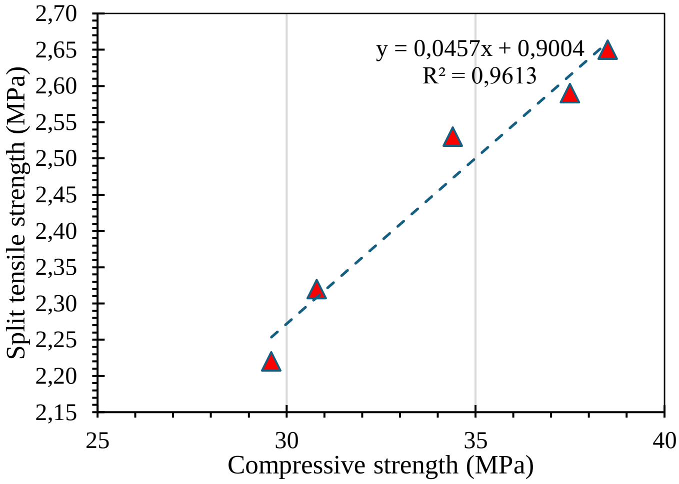

Figure 5. The correlation between CS and STS.

iv. Drying Shrinkage

Concrete undergoes volume reduction during the drying phase, referred to as drying shrinkage (DS). Historically, strain capacity has been regarded as a long-term attribute of concrete; however, Holt et al. [17] demonstrated that it is particularly susceptible to internal stresses shortly after pouring. Similarly, Zhang et al. [18] noted that the tensile strain capacity of concrete is notably low during the initial stages of curing. SCC differs from traditionally vibrated concrete by having a lower coarse aggregate content (less than 60%) and a greater proportion of cement, admixtures, supplementary materials, and superplasticizers. This difference results in initial DS changes for SCC being more complex than those occurring later on [19].

Figure 6 illustrates the effect of the MTL fraction on the early DS of the MTLS slurry. In all groups, the DS deformation of MTLS increased rapidly at first before tapering off. A previous study [20] reported that all experimental samples exhibited a significant increase in shrinkage strain within the first 1450 minutes, achieving over 64.73% of the total DS rate observed at 72 hours. This initial shrinkage is attributed to the high heat of hydration produced during the hardening of the cement paste, which accelerates water evaporation and subsequent shrinkage. The figure further indicates that, compared to the control group SCC0, the DS of MTLS rose as the MTL substitution fraction increased, showing increments of 7.21%, 22.39%, 43.19%, and 66.15%. Research indicates that incorporating MTL into concrete elevates its free water content [9], resulting in increased paste and higher DS in SCC.

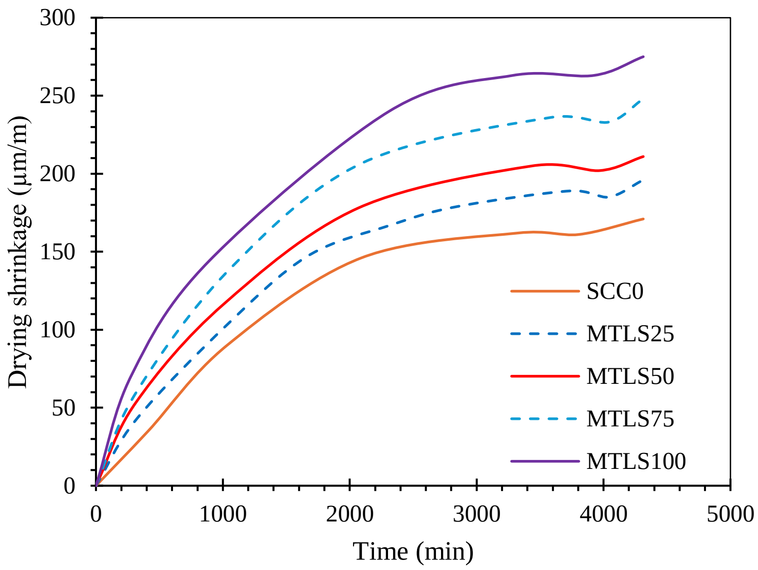

Figure 6. The drying shrinkage of SCC with various substitution ratio of MTL.

IV. CONCLUSIONS

From the study, the following findings may be made:

- The workability of fresh SCC was negatively impacted by the addition of MTL. T500, VF, and SF-JF values increased as MTL substitution increased, but SF and JF values declined. The air content rose at first, but then it fell. While SCC combinations with 50% MTL fulfilled standard standards, those with 25% MTL showed acceptable fresh characteristics. The viscosity of SCC mixes rose when MTL substitution surpassed 50%, indicating that a higher superplasticizer content might be advantageous.
- A larger MTL substitution fraction was associated with an increase in the early drying shrinkage of SCC combinations. With a 25% MTL substitution, sustainable SCC with a drying shrinkage like SCC0 is possible. From the first setting to 24 hours, there was a rapid stage of drying shrinkage that accounted for 65%–72% of the overall drying shrinkage at 72 hours.
- At 3 days, MTLS samples showed significant CS improvements over SCC0: 32.96%, 24.27%, 15.89%, and 12.86%. By 7 and 14 days, CS reached 75% and 85% of 28-day strength. SCC0 had a higher strength growth rate due to GGBS's stronger hydration activity.
- Most SCC holes are tiny—less than 100 nm. In comparison to the control, the percentage of pores less than 100 nm rose with 25% MTL, while the fraction of bigger pores (>100 nm) declined. SCC with 25% MTL had a denser pore structure, which increased its strength.

REFERENCES

[1] Okamura, H. and M. Ouchi, Self-compacting concrete. Journal of advanced concrete technology, 2003. 1(1): p. 5-15.

[2] Nguyen, H.-A., T.-P. Chang, and J.-Y. Shih, Effects of sulfate rich solid waste activator on engineering properties and durability of modified high volume fly ash cement based SCC. Journal of Building Engineering, 2018. 20: p. 123-129.

[3] Mohan, A. and K. Mini, Strength and durability studies of SCC incorporating silica fume and ultra fine GGBS. Construction and Building Materials, 2018. 171: p. 919-928.

[4] Al-Oran, A.A.A., N.A. Safiee, and N.A.M. Nasir, Fresh and hardened properties of self-compacting concrete using metakaolin and GGBS as cement replacement. European Journal of Environmental and Civil Engineering, 2022. 26(1): p. 379-392.

[5] Dinakar, P., K.P. Sethy, and U.C. Sahoo, Design of self-compacting concrete with ground granulated blast furnace slag. Materials & Design, 2013. 43: p. 161-169.

[6] Tadi, C. and T.C. Rao, Investigating the performance of self-compacting concrete pavement containing GGBS. Materials Today: Proceedings, 2022. 49: p. 2013-2018

[7] Mohamed, O.A. and O.F. Najm, Compressive strength and stability of sustainable self-consolidating concrete containing fly ash, silica fume, and GGBS. Frontiers of Structural and Civil Engineering, 2017. 11: p. 406-411

[8] Esquinas, A., et al., Mechanical and durability behaviour of self-compacting concretes for application in the manufacture of hazardous waste containers. Construction and Building Materials, 2018. 168: p. 442-458.

[9] Luo, T., et al., Early-age hydration and strength formation mechanism of composite concrete using molybdenum tailings. Case Studies in Construction Materials, 2022. 16: p. e01101.

[10] Erdoğdu, Ş., C. Arslantürk, and Ş. Kurbetci, Influence of fly ash and silica fume on the consistency retention and compressive strength of concrete subjected to prolonged agitating. Construction and Building Materials, 2011. 25(3): p. 1277-1281.

[11] Quan, X., et al., Utilization of molybdenum tailings as fine aggregate in recycled aggregate concrete. Journal of Cleaner Production, 2022. 372: p. 133649.

[12] Guo, Y., et al., Pore structure characteristics and performance of construction waste composite powder-modified concrete. Construction and Building Materials, 2021. 269: p. 121262.

[13] Liu, K., et al., Study on the mechanical properties and microstructure of fiber reinforced metakaolin-based recycled aggregate concrete. Construction and Building Materials, 2021. 294: p. 123554.

[14] Parra, C., M. Valcuende, and F. Gómez, Splitting tensile strength and modulus of elasticity of self-compacting concrete. Construction and Building materials, 2011. 25(1): p. 201-207.

[15] Holt, E. and M. Leivo, Cracking risks associated with early age shrinkage. Cement and Concrete Composites, 2004. 26(5): p. 521-530.

[16] Tao, Z. and Q. Weizu, Tensile creep due to restraining stresses in high-strength concrete at early ages. Cement and Concrete Research, 2006. 36(3): p. 584-591.

[17] Hwang, S.-D. and K.H. Khayat, Effect of mixture composition on restrained shrinkage cracking of self-consolidating concrete used in repair. ACI Materials journal, 2008. 105(5): p. 499.

[18] Shi, J., et al. Experimental Study on Early Drying Shrinkage of Self-compacting Barite Concrete. in Journal of Physics: Conference Series. 2021. IOP Publishing.

[19] Zhu, W., et al., Understanding restraint effect of coarse aggregate on the drying shrinkage of self-compacting concrete. Construction and Building Materials, 2016. 114: p. 458-463.

[20] Choudhary, R., et al. Permeation, corrosion, and drying shrinkage assessment of self-compacting high strength concrete comprising waste marble slurry and fly ash, with silica fume. in Structures. 2021. Elsevier.