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Experimental Study of Effect of Glass Fibres on Properties of Concrete Containing Micro-silica and Limestone Powder

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Abstract

The purpose of this work is to investigate the possibility of using mine wastes in the improvement of concrete properties. This research work investigates the physical and mechanical properties of the concrete specimens. These concrete specimens include concrete-lacking fibres, micro-silica and limestone powder (C), concrete-containing glass fibres without micro-silica and limestone powder (GC), concrete-containing micro-silica and limestone powder without fibres (CML), and concrete-containing glass fibres, micro-silica, and limestone powder (CGML). The physical and mechanical properties including the effective porosity, longitudinal wave velocity, water absorption, unit weight, tensile strength, uniaxial compressive strength, triaxial compressive strength, cohesion, and internal friction angle are investigated. The results obtained show that adding glass fibres to the concrete (GC) improve its properties compared to the fibre-less concrete (C). However, the properties of GC are improved significantly less than CGML. The Brazilian tensile strength and uniaxial compressive strength of GC increase by 13.6% and 10.95% relative to C. The Brazilian tensile strength and uniaxial compressive strength of CGML increase by 21.8% and 45.94% relative to C. Finally, it can be concluded that adding the micro-silica and limestone powder to the glass fibre concrete as well as the use of mine wastes also significantly improves the properties of the concrete.

1. Introduction

As a synthetic rock, concrete has secured a special place in the construction industry and support systems of underground spaces [1], and thus was selected as the subject of this work. Cement is one of the commodities used in large quantities for the construction of concrete, yet increasing ~~the~~ cement production leads to environmental pollution. The recent scientific and technological advancements have offered partial substitutes for cement in the concrete mix [2] that better address the economic and environmental concerns. The use of mine wastes or tailings means the removal of such tailings from the environmental viewpoint and the elimination of material depot and storage costs from the economical viewpoint [2].

Micro-silica and limestone powder are among the wastes that replace part of the cement. Limestone powder is an inactive material that is obtained as a by-product of the process of cutting, shaping, and polishing limestone, and causes environmental problems. Micro-silica is a by-product obtained from the reduction of very pure quartz with coal in an electric arc furnace when producing a ferrosilicon or silicon alloy [3].

Non-reinforced concrete is brittle, limiting its widespread applications. This major drawback can be addressed by reinforcing concrete with steel rebar or reinforcement. However, reinforcement involves a small part of the section and assuming that the concrete section is a homogeneous isotropic section seems incorrect. Moreover, rebar corrosion in reinforced concrete is among the

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reasons for the failure of the reinforced concrete structure and the most prevalent type of concrete failure on the shores.

Thin fibres homogeneously dispersed in concrete have been extensively used in the recent decades in order to provide isotropic conditions and reduce concrete brittleness. The physical properties of fibre-reinforced concrete are significantly affected by the fibre properties including the volumetric ratio of fibres, fibre type and orientation, and fibre-matrix bonding [4].

Unlike the polymeric materials with a chain structure, glass has a network (lattice) structure. Nonetheless, the strength of glass fibres is very high, almost twice the strength of other non-metallic fibres. Glass fibres are fine flexible fibres formed from molten glass as filaments. Glass fibres show high chemical resistance, moisture resistance, electrical insulation, good physical properties, high tensile strength, and good thermal resistance [5].

Most studies have investigated concrete containing different fibres or concrete containing micro-silica and limestone powder without fibres. Some studies on the properties of fibre-reinforced concrete are reviewed below.

Miloud et al. (2005) have studied the effect of steel fibres on the concrete porosity and permeability. According to their results, despite decreased porosity due to increased vibration time of fibre-reinforced concrete than conventional concrete, the permeability of fibre-reinforced concrete increase due to the fact that fibres act as bridges between pores [6].

Choi and Yuan (2005) have found that the compressive strength of reinforced concrete containing 1% and 1.5% glass fibres, respectively, decrease by 27.5% and 29.3% but the tensile strength, respectively, increase by 11% and 21% [7].

Karahan and Atis (2011) have investigated the effect of polypropylene (PP) fibres on the compressive strength and modulus of elasticity of concrete specimens reinforced by 0.05, 0.1, and 0.2 Vol.% of PP fibres. Their results revealed the negligible effect of PP fibres on the compressive strength and modulus of elasticity. The compressive strength of some specimens slightly decreased due to the vacant space formed by PP fibres and weak bonding between PP fibres and cement as well as improper vibration of fibre-reinforced concrete [8].

Taherifard et al. (2016) have found that the compressive strength of concrete reinforced with 0.1%, 0.2%, and 0.3% glass fibres, respectively, decrease by 0.8%, 2.8%, and 6.5% [9].

Hilles and Ziara (2019) have studied the effect of glass fibres on the compressive, tensile, and flexural (bending) strength of ultra-high-performance concrete (UHPC) containing 0.3, 0.6, 0.9, and 1.2 Wt.% glass fibres relative to cement. According to their results, by increasing the glass fibre content, the compressive strength increased from 58.85 MPa for fibre-less concrete to 66.6 MPa for concrete containing 1.2% glass fibres. The tensile strength increased from 3.06 MPa to 4.92 MPa and the flexural strength from 4.84 MPa to 7.27 MPa by increasing the glass fibre content from 0% to 1.2% [10].

A review of the previous research works shows that fibre concrete requires more vibration time to reduce porosity and increase its mechanical properties. Therefore, the idea of adding micro-silica and limestone powder was formed to reduce porosity and improve the mechanical properties.

Some studied on concrete-containing micro-silica or micro-silica and limestone powder are reviewed below.

Hasanzadeh et al. (2009) have studied the mechanical properties of the concrete specimens containing micro-silica as a partial cement substitute in concrete. The strength of 3- and 7-day specimens was compared with that of control specimens lacking micro-silica. They found that water absorption decreased by 37% due to filling pores by micro-silica. The compressive strength of almost all concrete specimens containing micro-silica increased by 13% relative to the control specimen. The unit weight of concretes containing micro-silica increased by 3.6%. The specimens containing 10% and 15% micro-silica showed almost the same compressive strength. The specimens containing 10% micro-silica showed a lower water absorption than those containing 15% micro-silica. The unit weight of the specimen containing 15% micro-silica was less than that of the specimen containing 10% micro-silica [11].

Ghalenoei et al. (2018) have investigated the effect of marble powder wastes and silica as partial cement substitutes on concrete durability and compressive strength. Marble powder wastes are inactive produced as a by-product from cutting, forming, and finishing marble causing environmental problems. In this experimental study, the durability of 16 concrete mix designs containing marble powder (0, 5, 10, and 20 Wt.% relative to cement) and micro-silica (0, 2.5, 5, and 10 Wt.% relative to cement) as partial cement substitutes were investigated. A constant water/cement material ratio of 0.45 was used. According to their results, the durability and strength of concrete containing marble powder decreased at replacement ratios larger than 10%. However, satisfactory results were obtained for replacement ratios up to 10% marble powder. Replacement ratios of 5% and 10% micro-silica compensated for the reduced durability of concrete containing high marble powder contents, while improving the durability properties of the specimens containing marble powder wastes [3].

Singniave et al. (2020) have investigated the effect of partial replacement of Portland cement with micro-silica and limestone powder on the UHPC properties. In these mixtures, part of cement was replaced with 10%, 15%, and 20% micro-silica and 15% and 20% limestone powder. A constant water/cement ratio of 0.2 and a steel fibre content of 2 Vol.% were considered for all mixtures. The specimens were cured by water vapour for 3 days. Their results obtained showed that micro-silica increased both the compressive and flexural strengths. In contrast, adding limestone powder caused a decrease in the compressive and bending strengths [12].

Mansouri et al. (2021) have investigated the effect of ceramic waste powder (CWP), micro-silica (MS), and steel fibres (SFs) on self-compacting mortar. CWP replaced 10% and 20% of cement and MS replaced 1% and 5% of cement. Moreover, 0.5% and 1% SF were added relative to cement. According to their results, CWP reduced the mechanical properties of self-compacting mortar by about 20% and increased its permeability by about 14%. In contrast, the micro-silica particles improved the mechanical properties of self-compacting mortar so that the compressive strength increased by about by 30% by adding MS [13].

A previous research work on the properties of concrete-lacking fibres containing micro-silica and rock powder shows that this concrete has a less porosity and a higher tensile strength and uniaxial compressive strength than concrete-lacking fibres without micro-silica and limestone powder.

According to the literature, most studies have investigated concrete-containing glass fibres or concrete-containing micro-silica and limestone powder without glass fibres. This work investigates the physical and mechanical properties of concrete-containing glass fibres, micro-silica, and limestone powder.

2. Materials and methods

The mixing ratio of the fibre-reinforced concrete is determined like the conventional concrete. However, fibres reduce the workability of the concrete mixture so that the workability further decreases by increasing the fibre length and content. Therefore, the following items should be applied for modifying the mixture in order to determine the concrete mixing ratio:

1. Reducing the sand content;
2. Increasing the cement content;
3. Increasing the gravel content;
4. Using super-lubricant;
5. Reducing the maximum sand size [14].

Calcareous sand and gravel were used in this work. Table 1 reports the XRF analysis of the sand composition. According to the screen analysis, the sand used in this work meets the requirements of National Standard No. 302, Institute of Standards & Industrial Research of Iran [15].

Table 1. XRF analysis of the sand and gravel samples.

Sample	Unit	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	SO_3	P_2O_5	MnO	TiO_2	L.O.I
Sand	%	3.3	0.9	0.6	< 0.1	0.2	52.8	0.6	< 0.1	< 0.1	< 0.1	< 0.1	41.4
Gravel	%	7.3	1.6	1	0.4	0.5	49.3	0.9	< 0.1	< 0.1	< 0.1	< 0.1	38.8

After testing the multiple mix designs by trial-and-error, the final concrete mix designs including the concrete-lacking fibres, micro-silica and limestone powder, concrete-containing glass fibres lacking micro-silica and limestone powder, concrete-lacking fibres containing micro-silica and limestone powder, and concrete-containing glass fibres, micro-silica, and limestone powder were presented. Three glass fibre contents of 0.2%, 0.35%, and 0.5% were studied. The lowest effective porosity and highest tensile strength were obtained for the concrete specimen containing 0.35 Vol.% glass fibres. Accordingly, a glass fibre content of 0.35 Vol.% was considered in the mix design of glass fibre-reinforced concrete.

Figure 1 displays the glass fibres and Table 2 reports their specifications. The mix designs are presented in Tables 3-6.

Figure 1. Glass fibres.

Table 2. Specifications of glass fibres [16].

Diameter (μm)	15-30
Density (g/cm3)	2.75
Modulus of elasticity (GPa)	70
Tensile strength (GPa)	3
Softening point (°C)	530-540
Melting point (°C)	550-560

Table 3. Mix design of concrete-lacking fibres, micro-silica, and limestone powder.

Components	Content per 1 m3 concrete
Portland cement type 2 (kg)	350
Sand (kg)	1150
Gravel (kg)	700
Water/cement ratio	0.4
Superplasticizer (kg)	2.8

Table 4. Mix design of concrete reinforced with glass fibres.

Components	Content per 1 m3 concrete
Portland cement type 2 (kg)	350
Sand (kg)	1150
Gravel (kg)	700
Water/cement ratio	0.4
Superplasticizer (kg)	2.8
Glass fibres (kg)	9.625

Table 5. Mix design of concrete-lacking glass fibres containing micro-silica and limestone powder.

Components	Content per 1 m3 concrete
Portland cement type 2 (kg)	297.5
Sand (kg)	1150
Gravel	700
Water/cement ratio	0.4
Superplasticizer (kg)	2.8
Micro-silica (kg)	35
Limestone powder (kg)	17.5

Table 6. Mix design of fibre glass-reinforced concrete containing micro-silica and limestone powder.

Components	Content per 1 m3 concrete
Portland cement type 2 (kg)	297.5
Sand (kg)	1150
Gravel (kg)	700
Water/cement ratio	0.4
Superplasticizer (kg)	2.8
Micro-silica (kg)	35
Limestone powder (kg)	17.5
Glass fibres (kg)	9.625

The physical and mechanical properties including the effective porosity, velocity of longitudinal waves, water absorption, unit weight, tensile strength, uniaxial compressive strength, triaxial compressive strength, cohesion, and internal friction angle were investigated.

Polyvinylchloride (PVC) pipes with an inner diameter of 59 mm were used to prepare the specimens. The mixture was poured into the mould and then removed after 24 h and stored in the laboratory up to 28 days in saturated lime water [17]. The specimens were removed from lime water after 28 days and cut into the desired lengths by a cutter and prepared for the Brazilian and uniaxial compressive strength tests. In addition to cutting, the uniaxial compressive specimens were also polished.

3. Results and discussion

3.1. Results

The physical properties including the effective porosity, dry unit weight, water absorption, and longitudinal wave velocity, and the mechanical properties including the Brazilian tensile strength, uniaxial compressive strength, and triaxial compressive strength were determined based on the ISRM standard.

3.1.1. Physical properties

3.1.1.1. Effective porosity

In order to determine the effective porosity, the dimensions of the specimens were precisely measured by callipers to calculate their volumes. The specimens were then saturated in water for 1 h under a vacuum pressure less than 800 Pa, and the saturated mass was calculated. The specimens were then stored in an oven at 105 °C for 6-7 h, and the dry mass was measured. The effective porosity was calculated from Eq. 1 [18].

$$n(e) = \frac{V_{ve}}{V} \times 100 \quad (1)$$

where:

V_{ve}: Volume of interconnected voids, V: Total volume.

V_{ve} = (Saturated mass- dry mass)/ρ_{water}

Five specimens were tested for each case in order to determine the effective porosity. Table 7 reports the mean results for the concrete specimens.

3.1.1.2. Velocity of longitudinal waves

In order to determine the longitudinal wave velocity, the receiver and transmitter transducers were marked on the end surfaces of the specimens so that the line passing through their centres did not differ more than 2° with the centre axis of specimens. The wave motion distance, the centre-to-centre distance of transducers, was then measured. A thin layer of Vaseline was applied on the location, where transducers were installed to prevent the reduction of energy passing through transducers.

Transducers were placed on the marked sites, and the transmitter was pressed on the specimen with a pressure equivalent to 10 N/cm^2, and the wave passage time was recorded [19]. In order to obtain the lost time between the specimen and the transducers, transducers were placed on each other, and the displayed time was subtracted from the recorded times. The longitudinal wave velocity in the specimens was calculated from Eq. 2 [19].

$$V_P = \frac{L}{\mathrm{t}} \times 1000 \quad (2)$$

where:

L: Sample length (mm), the wave passage time (μs).

Five specimens were tested for each case in order to determine the longitudinal wave velocity. Table 8 reports the mean results for the concrete specimens.

3.1.1.3. Dry unit weight and water absorption

The dry unit weight and water absorption were calculated from Eqs. 3 and 4, respectively [18].

$$\gamma_{dry} = \frac{W_S}{V} \quad (3)$$

$$WA = \frac{B-A}{A} \mathrm{x}100 \quad (4)$$

where γ_{dry} represents the dry unit weight, W_s if the dry weight, V is the total volume, B is the mass of specimen immersed in water after 48 h, A is the dry mass, and WA shows water absorption. Tables 9 and 10 report the mean results for the concrete specimens.

Table 7. Mean effective porosity of concrete specimens.

Concrete type	Effective porosity (%)
Without fibres	6.85
Reinforced with glass fibres	6.51
Without fibres containing micro-silica and limestone powder	4.35
Fibre-reinforced concrete containing micro-silica and limestone powder	4.17

Table 8. Mean longitudinal wave velocity in concrete specimens.

Concrete type	PV (m/s)
Without fibres	4745.3
Reinforced with glass fibres	4775.2
Without fibres containing micro-silica and limestone powder	4985.1
Fibre-reinforced concrete containing micro-silica and limestone powder	4997.7

Table 9. Mean dry unit weight of concrete specimens.

Concrete type	γ_{dry} (kN/m^3)
Without fibres	22.05
Reinforced with glass fibres	22.95
Without fibres containing micro-silica and limestone powder	23.27
Fibre-reinforced concrete containing micro-silica and limestone powder	23.35

Table 10. Mean water absorption of concrete specimens.

Concrete type	WA (%)
Without fibres	2.9
Reinforced with glass fibres	2.75
Without fibres containing micro-silica and limestone powder	2.17
Fibre-reinforced concrete containing micro-silica and limestone powder	2.05

3.1.2. Mechanical properties
3.1.2.1. Tensile strength

The Brazilian test was performed in order to determine the Brazilian tensile strength of the specimens. The tensile strength was calculated from Eq. 5 [20].

$$\sigma_t = 0.636\frac{P}{D.t} \qquad (5)$$

where P represents the load at failure (N), D is the specimen diameter (mm), t is the specimen thickness (mm), and σ_t is the tensile strength (MPa). Ten specimens were tested for each case in order to determine the tensile strength. Table 11 reports the mean results for the concrete specimens. Figure 2 displays the Brazilian test on the concrete specimens.

3.1.2.2. Uniaxial compressive strength

The uniaxial compressive test was performed in order to determine the uniaxial compressive strength of the specimens [21]. Five specimens were tested for each case to determine the uniaxial compressive strength. Table 12 reports the mean results for the concrete specimens.

3.1.2.3. Triaxial compressive strength, cohesion, and internal friction angle

The triaxial compressive test was performed in order to determine the triaxial compressive strength, cohesion, and internal friction angle. The test instrument includes the four distinct sections of the Hook's test cell, axial load jack, confining pressure pump, and specimen removal jack. The tests were performed based on the ISRM standard [22] under a confining pressure of 2.5 and 5 MPa. 5 tests were performed on the samples of each type of concrete at each confining pressure. Table 13 reports the average results for the concrete specimens.

The test results are presented in Figs. 3 to 6.

Figure 2. Brazilian test on the concrete specimens.

Table 11. Mean Brazilian tensile strength of concrete specimens.

Concrete type	σ_t (MPa)
Without fibres	4.85
Reinforced with glass fibres	5.51
Without fibres containing micro-silica and limestone powder	5.78
Fibre-reinforced concrete containing micro-silica and limestone powder	5.91

Table 12. Mean uniaxial compressive strength of concrete specimens.

Concrete type	σ_C (MPa)
Without fibres	29.95
Reinforced with glass fibres	33.23
Without fibres containing micro-silica and limestone powder	40.53
Fibre-reinforced concrete containing micro-silica and limestone powder	43.71

Table 13. Mean triaxial compressive strength of concrete specimens.

Concrete type	Confining pressure (MPa)	Triaxial compressive strength (MPa)
Without fibres	2.5	45.75
Without fibres	5	55.72
Reinforced with glass fibres	2.5	47.65
Reinforced with glass fibres	5	59.35
Without fibres containing micro-silica and limestone powder	2.5	51.67
Without fibres containing micro-silica and limestone powder	5	73.75
Fibre-reinforced concrete containing micro-silica and limestone powder	2.5	57.85
Fibre-reinforced concrete containing micro-silica and limestone powder	5	79.68

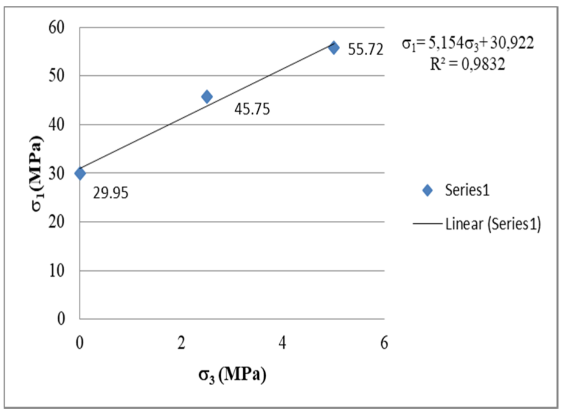

Figure 3. Failure envelope for fibre-less concrete.

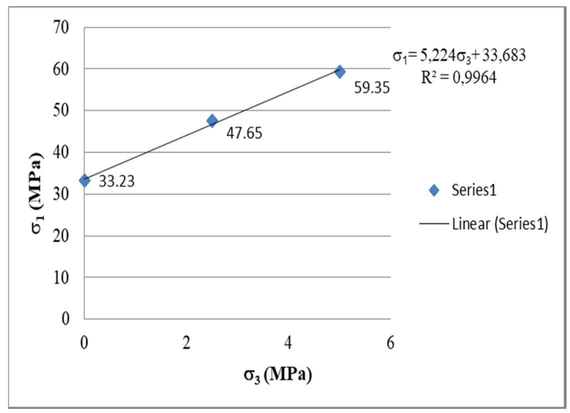

Figure 4. Failure envelope for concrete reinforced with glass fibres.

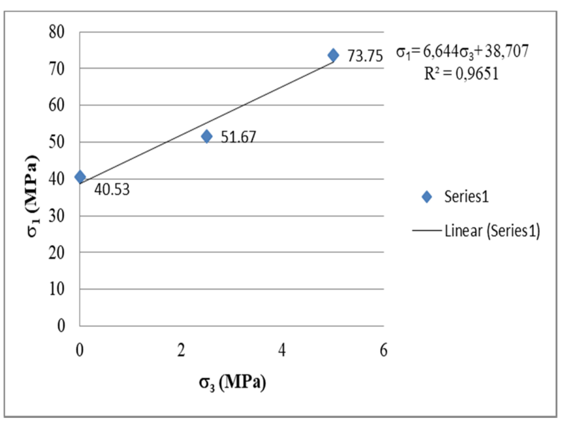

Figure 5. Failure envelope for concrete without fibres containing micro-silica and limestone powder.

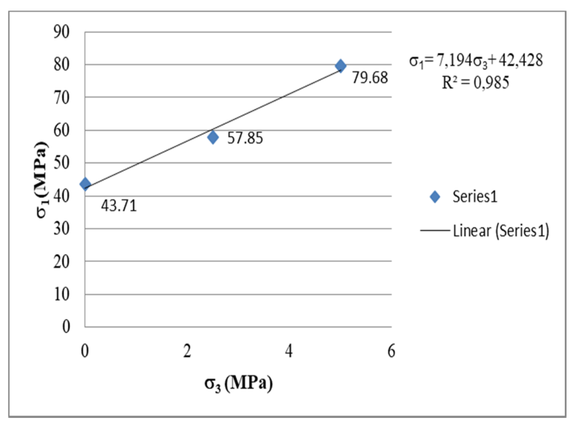

Figure 6. Failure envelope for fibre-reinforced concrete containing micro-silica and limestone powder.

The internal friction angle and cohesion of the concrete specimens were calculated from Eqs. 6 and 7, respectively [23].

$$\emptyset = \sin^{-1}\frac{m-1}{m+1} \tag{6}$$

$$C = b\frac{1-\sin\emptyset}{2\cos\emptyset} \tag{7}$$

where Ø represents the internal friction angle (°), C is the cohesion (MPa), m is the axial stress-confining pressure curve slope, and b is the intercept of the axial stress-confining pressure curve. Table 14 reports the cohesion and internal friction angle of the concrete specimens.

3.2. Discussions

The concrete properties were displayed on the following diagrams in order to analyse the results. Figure 7 shows the effective porosity of the concrete specimens. On all diagrams, C represents the concrete-lacking glass fibres, GC is the glass fibre-reinforced concrete, CML is the concrete-lacking glass fibres containing micro-silica and limestone powder, and CGML shows the glass fibre-reinforced concrete containing micro-silica and limestone powder.

As shown in Fig. 7, the effective porosity of CGML, CML, and GC is reduced by 39.1%, 36.4%, and 4.96%, respectively, relative to C. These results are consistent with those obtained by Miloud [6] who found that the fibre-reinforced concrete had the lower effective porosity than the fibre-less concrete. Our results are also consistent with those reported by Hasanzadeh et al. [11]. In other words, micro-silica and limestone powder fill the concrete pores leading to a lower effective porosity than the conventional concrete. Figure 8 shows the longitudinal wave velocity in the concrete specimens.

Table 14. Cohesion and internal friction angle of concrete specimens.

Concrete type	C (MPa)	∅ (°)
Without fibres	6.81	42.46
Reinforced with glass fibres	7.38	42.74
Without fibres containing micro-silica and limestone powder	7.51	47.59
Fibre-reinforced concrete containing micro-silica and limestone powder	7.91	49.11

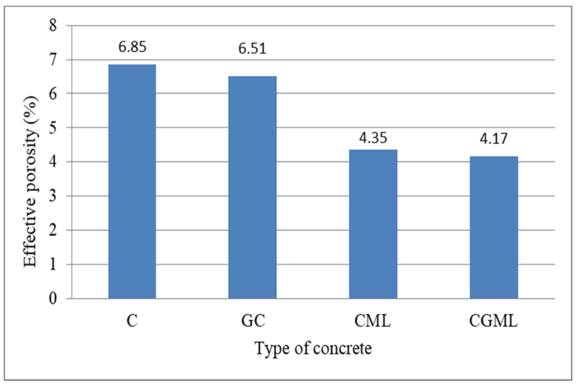

Figure 7. Effective porosity of concrete specimens.

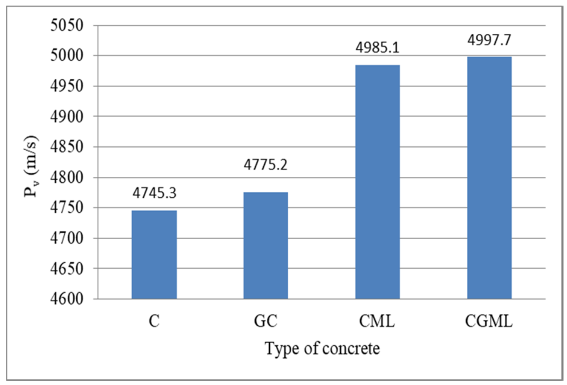

Figure 8. Longitudinal wave velocity in concrete specimens.

As shown in Fig. 8, the longitudinal wave velocity increases by adding fibres, micro-silica, and limestone powder, consistent with the reduced effective porosity. The longitudinal wave velocity increased by 5.31% in CGML compared to C. Figures 9 and 10, respectively, show the dry unit weight and water absorption of the concrete specimens. As shown, the dry unit weight increases but water absorption decreases by adding glass fibres, micro-silica, and limestone powder, consistent with the results of Hasanzadeh *et al.* [11]. The changes in the dry unit weight and water absorption are also consistent with the effective porosity variations so that the effective porosity decreases, dry unit weight increases, and water absorption decreases by filling the concrete pores with glass fibres, micro-silica, and limestone powder. The changes in the dry unit weight in this research work are consistent with the results of Ghalenoei *et al.* (2018) [3].

According to the results obtained, the dry unit weight and water absorption of CGML decreased by 5.89% and 29.3% than C, respectively.

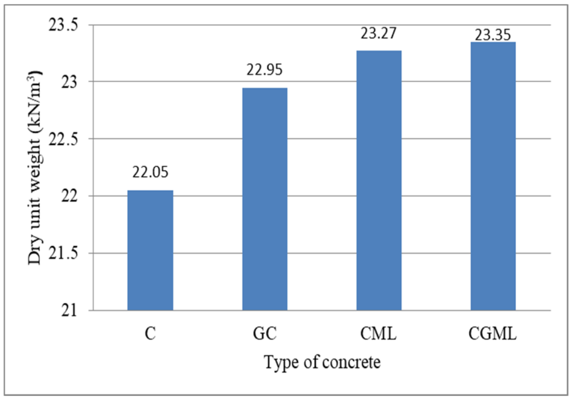

Figure 9. Dry unit weight of concrete specimens.

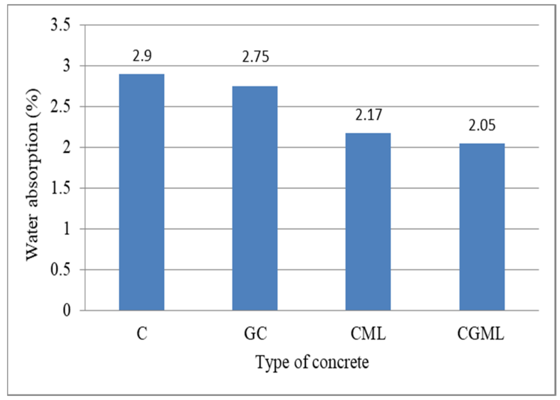

Figure 10. Water absorption of concrete specimens.

Figures 11 and 12 display the Brazilian tensile strength and uniaxial compressive strength of the concrete specimens. As shown, the Brazilian tensile strength and uniaxial compressive strength increase by adding glass fibres, micro-silica, and limestone powder, consistent with the results of Singniave et al. [12] and Mansouri et al. [13]. The porosity decreases by adding glass fibres, micro-silica, and limestone powder, leading to an increase in the Brazilian tensile strength and the uniaxial compressive strength. The Brazilian tensile strength and uniaxial compressive strength of CGML, respectively, increased by 21.8% and 45.94% relative to C. The changes in the Brazilian tensile strength and the uniaxial compressive strength in this research work are consistent with the results of Ghalenoei et al. (2018) [3].

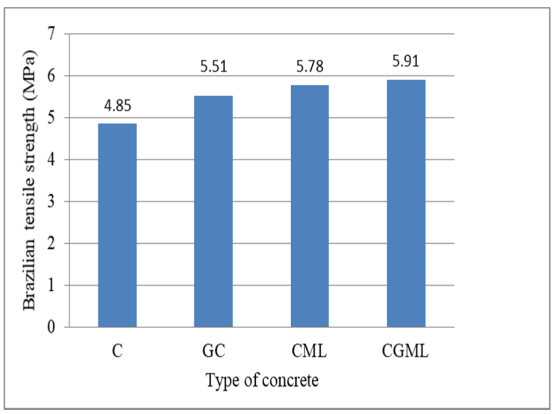

Figure 11. Brazilian tensile strength of concrete specimens.

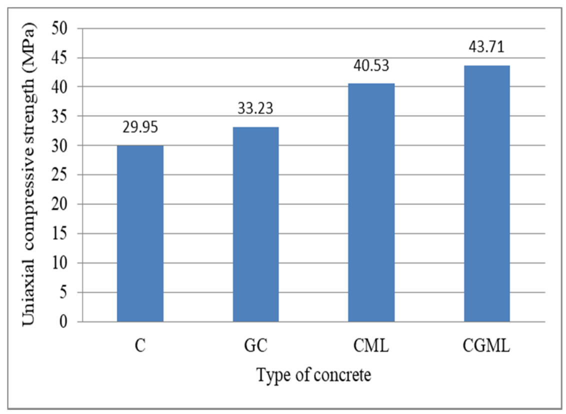

Figure 12. Uniaxial compressive strength of concrete specimens.

Figure 13 shows the triaxial compressive strength of the concrete specimens at the confining pressures of 2.5 MPa and 5 MPa. As shown, CGML has a higher triaxial compressive strength than C so that the triaxial compressive strength of CGML at the confining pressures of 2.5 MPa and 5 MPa, respectively, increases by 26.44% and 43% relative to C.

The higher triaxial compressive strength of CGML than C can be related to its lower porosity and the presence of glass fibres. Figures 14 and 15 show the cohesion and internal friction angles of the concrete specimens.

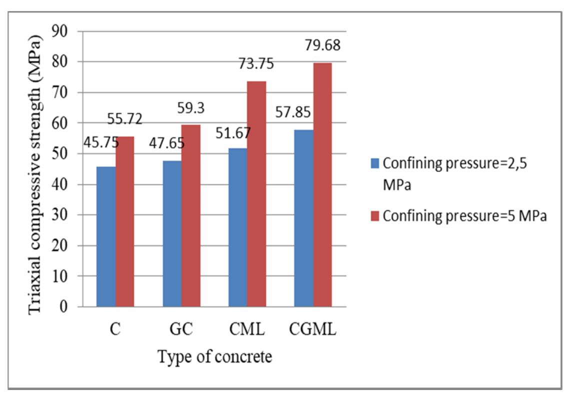

Figure 13. Triaxial compressive strength of concrete specimens at $\sigma_3 = 2.5$ MPa and $\sigma_3 = 5$ MPa.

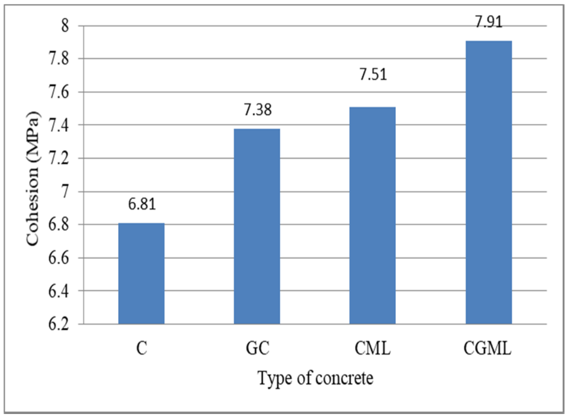

Figure 14. Cohesion of concrete specimens.

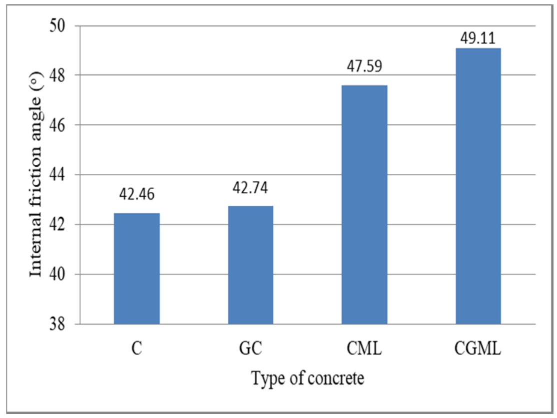

Figure 15. Internal friction angle of concrete specimens.

As shown, the cohesion and internal friction angles of CGML increase by 16.15% and 15.66% than C. Adding glass fibres to the concrete (GC) improves the concrete properties than the fibre-less concrete (C). However, the GC properties are considerably less improved in comparison with CGML so that the effective porosity, longitudinal wave velocity, dry unit weight, water absorption, Brazilian tensile strength, uniaxial compressive strength, cohesion, and internal friction angle of GC, respectively, decreased by 4.96%, increased by 0.63%, 4.08%, decreased by 5.17%, and increased by 13.6%, 10.95%, 8.37%, and 0.65% relative to C.

5. Conclusions

The physical and mechanical properties of the concrete specimens lacking glass fibres, micro-silica, and limestone powder containing glass fibres lacking micro-silica, and limestone powder, lacking glass fibres containing micro-silica and limestone powder, and specimens containing glass fibres, micro-silica, and limestone powder were investigated. The main results obtained can be summarized as follow:

- The effective porosity and velocity of longitudinal waves in GC, respectively, decreased and increased by 4.96% and 0.63% relative to C. The effective porosity and velocity of longitudinal waves in CML, respectively, decreased and increased by 36.49% and 5.05% relative to C. The effective porosity and velocity of longitudinal waves in CGML, respectively, decreased and increased by 39.1% and 5.31% relative to C.
- The dry unit weight and water absorption of GC, respectively, increased and decreased by 4.08% and 5.17% relative to C. The dry unit weight and water absorption of CML, respectively, increased and decreased by 5.53% and 25.17% relative to C. The dry unit weight and water absorption of CGML, respectively, increased and decreased by 5.89% and 29.3% relative to C.
- The Brazilian tensile strength and uniaxial compressive strength of GC, respectively, increased by 13.6% and 10.95% relative to C. The Brazilian tensile strength and uniaxial compressive strength of CML, respectively, increased by 19.17% and 35.32% relative to C. The Brazilian tensile strength and uniaxial compressive strength of CGML, respectively, increased by 21.8% and 45.94% relative to C.
- The cohesion and internal friction angles of GC, respectively, increased by 8.37% and 0.65% relative to C. The cohesion and internal friction angles of CML, respectively, increased by 10.27% and 12.08% relative to C. The cohesion and internal friction angles of CGML, respectively, increased by 16.15% and 15.66% relative to C.
- In addition to the consuming mine wastes and tailings, adding micro-silica and limestone powder to the glass fibre-reinforced concrete is essential from the environmental and economical viewpoints. The properties of the concrete are also significantly improved by adding micro-silica, limestone powder, and glass fibres.

It is suggested that in a future work, the effect of glass fibres on the properties of concrete-containing nano-silica and limestone powder is investigated.

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مطالعه آزمایشگاهی اثر الیاف شیشه بر خواص بتن حاوی میکروسیلیس و پودر سنگ آهک

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چکیده:

هدف از این کار بررسی امکان استفاده از ضایعات معدنی در بهبود خواص بتن است. این کار تحقیقاتی به بررسی خواص فیزیکی و مکانیکی نمونه‌های بتن می پردازد. این نمونه‌های بتن شامل بتن بدون الیاف و فاقد میکرو سیلیس و پودر سنگ آهک (بتن C)، بتن دارای الیاف شیشه و فاقد میکرو سیلیس و پودر سنگ آهک (بتن GC)، بتن بدون الیاف و حاوی میکرو سیلیس و پودر سنگ آهک (بتن CML) و در نهایت بتن دارای الیاف شیشه و حاوی میکرو سیلیس و پودر سنگ آهک (بتن CGML) است. خواص فیزیکی و مکانیکی که در این پژوهش مورد مطالعه قرار گرفته است عبارت است از: تخلخل موثر، سرعت امواج طولی، جذب آب، وزن مخصوص، مقاومت کششی و مقاومت فشاری تک محوری. نتایج این پژوهش نشان می‌دهد که افزودن الیاف شیشه‌ای به بتن (بتن GC) باعث بهبود خواص بتن نسبت به بتن بدون الیاف (بتن C) می‌شود اما این بهبود خواص در بتن GC در مقایسه با بهبود خواص در بتن CGML بسیار کمتر است. مقاومت کششی برزیلی و مقاومت فشاری تک محوری در بتن GC نسبت به بتن C به ترتیب ۱۳/۶ درصد افزایش و ۱۰/۹۵ درصد افزایش و در بتن CGML نسبت به بتن C به ترتیب ۲۱/۸ درصد افزایش و ۴۵/۹۴ درصد افزایش می‌یابد. در نهایت، می‌توان نتیجه گرفت که افزودن میکروسیلیس و پودر سنگ آهک به بتن الیاف شیشه و همچنین استفاده از ضایعات معدنی نیز به طور قابل توجهی خواص بتن را بهبود می‌بخشد.

کلمات کلیدی: بتن، میکروسیلیس، پودر سنگ آهک، الیاف شیشه، خواص فیزیکی و مکانیکی.