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Influence of Retempering with Superplasticizer on Fresh and Hardened Properties of Prolonged Mixed Concretes Containing Supplementary Cementitious Materials

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Abstract: Ready-mixed concrete suffers in terms of fresh and hardened properties as a result of prolonged mixing, hot weather concreting and/or possible delays in construction site. To overcome these problems, this study focused on the provision of sufficient workability with the retempering of concrete mixtures during prolonged mixing periods with use of superplasticizer (SP). Four mixtures with substitution of different mineral admixtures such as blast furnace slag (BFS), fly ash (FA), ground clay brick (GCB) and natural pozzolan (NP) and control mixture were designed. 5, 60, 120, 180 and 240 minutes mixing periods were applied on the mixtures. 15 ± 2 cm slump value was targeted after the retempering. In addition, air content, 7 and 28 day compressive and splitting tensile strength of the mixtures were tested. Results showed that slump values fall to zero after prolonged mixing when mixtures were not retempered, while slump loss was completely eliminated after retempering with SP. The air content of the mixtures decreased significantly as a result of the stiffening of the concrete after prolonged mixing. After the retempering process, compressive and splitting tensile strengths of the mixtures slightly increased. Also, the fresh and hardened properties of concrete improved with the use of high amounts of mineral admixtures.

Keywords: air entrainment; mineral admixture; prolonged mixing; ready mixed concrete; retempering; superplasticizer

1 INTRODUCTION

Concrete that is prepared in factories or in a batching plant and delivered to the site via a truck mixer in a fresh and unhardened state is called ready-mixed concrete. The production and delivery of ready-mix concrete are carried out by a supplier that employs standard operational methods, making it easier to control the quality and standards of ready-mixed concrete in comparison to concrete made on-site. Advantages such as controllability of proportioning of ingredients, workability, compressive strength, high-speed construction, and constant quality standard of the ready-mix concrete make it more useful and feasible than the conventional concrete manufactured on-site [1, 2]. However, significant issues may arise when using ready-mixed concrete, particularly during extended mixing durations and hot weather conditions. As frequently seen in ready-mixed concrete applications, long transportation distances, traffic jams and possible delays at the construction site might result in the prolonged mixing of concrete. Prolonged mixing causes the mixture water to evaporate and/or initiate cement hydration and thus loss of slump value of the concrete as a result of beginning the stiffness of concrete [3, 4]. The higher water absorption rate of aggregates can be another reason for the slump loss of prolonged mixed concrete [4]. Coarse aggregates, particularly limestone and weakly cemented sandstone, tend to break down into fine aggregates as a result of the grinding action of prolonged mixing [5]. As a result, the slump value of the mixture decreases since the fine aggregates require more water to achieve the same consistency [6]. Besides the prolonged mixing, hot weather conditions also have a great impact on the fresh properties of the mixture. Hot weather conditions cause an increase in the heat of hydration and accelerate the evaporation rate of the mixing water resulting in a higher amount of slump loss. In addition, the temperature rises in the drum of the truck mixer resulting from prolonged mixing is another factor that triggers the loss of consistency, as it causes an increase in the cement hydration degree and the free water to evaporate [7].

Slump loss, or the loss of concrete consistency, has a detrimental impact on the workability of the concrete, reduces the ultimate compressive strength, and causes durability issues in the final product [8, 9]. Although commencing the discharge of concrete with a larger slump value than targeted may be assumed to be a remedy for slump loss in some situations, it may be argued that this is neither relevant nor practicable. For this reason, adding extra water or admixtures to the mixture to achieve the targeted slump value just before pouring, also known as retempering, may be ideal to minimize slump loss [10]. The most important reasons of need for retempering are insufficient water batched initially, a higher rate of evaporation and/or absorption and higher degree of hydration than expected. In the case of insufficient water in the batch or evaporation of water, retempering can be utilized with the use of extra water. However, in other cases, restoring the slump value with the addition of extra water is generally undesirable as it increases the water/binder ratio of the mixture and causes a catastrophic effect on the compressive strength and durability of the concrete [11]. Also, it has been stated that adding extra water to minimize slump loss is not practicable since a higher initial slump will result in a higher slump loss [12]. Therefore, it has been highly recommended that water reducer admixtures or superplasticizers are utilized to compensate for targeted slump value rather than adding extra water [11, 13, 14]. As it is known, the proper using of water-reducing additives and superplasticizers offers substantial advantages in enhancing concrete workability without loss in compressive strength [3, 15]. It has been reported that retempering concrete with the use of water showed a decrease in the compressive strength of the mixture by 40% compared to the reference sample after a mixing period of 150 minutes; on the other hand, an increase in compressive strength by about 30% was observed with the using of superplasticizer in the retempering operation [7]. As a result, particularly in hot weather concreting with extended mixing times, retempering operation using water-reducing admixtures and/or superplasticizer might be regarded useful to the concrete in terms of achieving the desired workability.

Several researches have been published in the literature to investigate the influence of supplementary cementitious materials (SCMs) (i.e., fly ash, ground granulated blast furnace slag, silica fume, etc.) on the rheological characteristics of cementitious composites. It has been stated that the inclusion of fly ash as a partial replacement for cement reduces slump loss by lowering the amount of cement in the mixture and increasing the setting time [16].

The authors also stated that slump loss of the concrete increased with the increase of fly ash fineness due to the finer fly ash having a larger surface area for interacting with water. Physical and chemical mechanisms were shown to be responsible for the effect of fly ash on minimizing slump loss in one investigation. The authors stated that as a result of coating the surface of fly ash with alkali sulfate, they were able to delay the synthesis of aluminate and hence the hydration of C3A [17]. According to a study to observe the effect of slag substitution on the loss of slump value, it was found that slump values between 0 - 90 minutes changed to 260 - 250 mm, 270 - 260 mm and 260 - 240 mm in the control mixture and mixtures containing 15% and 30% slag, respectively [18]. It has also been reported that due to the smooth and compact particle structure of the slag, mixtures containing slag have better workability with less water demand [19, 20]. It has been reported that the mixture containing natural zeolite as a natural pozzolan experienced less slump loss compared to the control specimen [21]. Also, the authors stated that the slump losses of mixtures with a water/cement ratio of 0.40 were 3.8 and 3.0 times of mixtures with a water/cement of 0.36 for an elapsed time of 30 and 60 min, respectively. According to all the above-mentioned findings, it can be stated that SCMs can be successfully utilized in concretes in order to overcome issues arising from slump loss as a result of prolonged mixing, hot weathering concrete and/or delays in construction sites.

In this study, the main emphasis is placed on the investigation of the effect of retempering with superplasticizer on the fresh and hardened properties of prolonged mixed concrete incorporating a high dosage of mineral admixtures such as fly ash, ground granulated blast furnace, natural pozzolan and clay brick. In this context, one control mixture and four mixtures with 50% mineral admixture substitution were designed within the scope of the study. The retempering operation was applied to the mixtures to achieve the targeted slump value of 15 ± 2 cm with the addition of SP after the first five minutes, and until 4 hours once an hour. The temperature was aimed to be 40 ± 5 Cº and the humidity was aimed to be 20 ± 10% during concreting operation. At the end of the retempering process, fresh and hardened tests such as slump test, air content measurement, compressive and splitting tensile strength tests were applied to all mixtures. Given the environmental impact of Portland cement in recent years, the use of alternative materials in the construction industry has become increasingly popular. Therefore, this study is highly innovative as it aims to produce a solution for retempering in prolonged mixing by replacing a significant proportion of Portland cement with alternative materials.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Ordinary Portland cement (OPC) was used as the main binder phase in the study. The chemical composition and physical properties of OPC were given in Tab. 1. Class F fly ash (FA), blast furnace slag (BFS), granulated clay brick (GCB) and natural pozzolan (NP) were utilized in the study as supplementary cementitious materials (SCMs). The chemical composition and physical properties of SCMs were presented in Tab. 2.

Table 1 Chemical composition and physical properties of the OPC

Chemical compositions / %	
SiO_2	20.47
Al_2O_3	5.68
Fe_2O_3	3.08
CaO	62.56
MgO	1.80
SO_3	3.22
Na_2O	0.30
K_2O	0.95
Loss on ignition / %	2.49
Insoluble residue / %	0.47
Physical properties	
Specific gravity	3.12
Blaine fineness / m^2/kg	392
Initial setting time / min	108
Final setting time / min	162
Compressive strength / MPa 3 days	27.6
Compressive strength / MPa 7 days	39.0
Compressive strength/ MPa 28 days	47.7

Table 2 Chemical composition and physical properties of SCMs

	FA	BFS	GCB	NP
Chemical compositions / %				
SiO_2	58.44	36.88	62.7	62.23
Al_2O_3	18.79	15.20	17.1	15.16
Fe_2O_3	10.60	0.70	6.84	3.27
CaO	3.34	35.48	3.94	4.93
MgO	4.52	9.95	2.25	1.51
SO_3	1.75	0.23	0.84	0.5
Loss on ignition	0.77	0.49	2.67	6.12
Physical properties				
Specific gravity	2.10	2.83	2.64	N/A
Specific surface area / m^2/kg)	289	469	400	443

An air-entraining admixture of Sika (AER) and ASTM C 494 Type G superplasticizer of Sika (Sikament 520 T) was used in all concrete mixtures [22]. Air entraining admixture with aratio of 0.25% and SP with a ratio of 1.25% of the total weight of the binder was used in all mixtures. For retempering process, ASTM C 494 Type F superplasticizer of Turkish firm KONSAN (HS 100) was used at different amounts to reach the targeted slump value of 15 ± 2 cm for all mixtures [22]. Crushed quartzite-type aggregate was used in the study with a nominal maximum aggregate size of 10 mm. Two different size groups of aggregates were combined to obtain proper gradation.

2.2 Proportions of Concrete Mixtures

A control mixture containing completely OPC as the binder phase and four concrete mixtures with 50% SCM substitution were designed within the scope of the study. The proportions of the concrete mixtures were given in Tab. 3. The control mixture was designed to achieve 30 MPa compressive strength at 28 day and 150 mm slump with 0.38 w/c and 400 kg/m^3 cement content. On the other hand, high-volume SCM mixtures were designed with 50% replacement of Portland cement by mass and 0.38 w/cm. The slump of the mixtures was adjusted to 15 ± 2 cm with the help of the superplasticizer.

Table 3 Proportions of the concrete mixtures

Material / kg/m^3	Control	50% FA	50% BFS	50% GCB	50% NP
OPC	400	200	200	200	200
FA	-	200	-	-	-
BFS	-	-	200	-	-
GCB	-	-	-	200	-
NP	-	-	-	-	200
Water	152	152	152	152	152
Aggregate	1910	1910	1910	1910	1910
Superplasticizer	5	5	5	5	5
Air-entraining admixture	0.4	0.4	0.4	0.4	0.4

2.3 Methods

The mixing operation was carried out in an isolated room at a temperature of 40 ± 5 ºC. A concrete mixer of 330 litres was used for prolonged mixing operation. After finishing of normal mixing operation at a normal mixing speed (about 20 revolutions per minute, for five minutes), 20% of concrete by weight (90 ± 10 kg) was taken out of the mixer. Extra water was added to bring the initial slump value of all mixtures to 15 cm when necessary. The remaining concrete continued to be mixed at a much slower speed, 4 revolutions per minute. After one hour of mixing, the mixer was stopped and the second 20% of concrete was taken out of the mixer. The slump was measured to find the value 15 ± 2 cm. If the slump value is under 13 cm, the retempering operation with superplasticizer proceeded to achieve the slump value of 15 ± 2 cm. For the retempering operation, the 20% portion was put into the second mixer. The superplasticizer was directly added to the second mixer during the mixing operation at 20 revolutions per minute. The amount of retempering agent is determined based on the slump value of 15 ± 2 cm of concrete in the mixer. After retempering operation, standard testing procedure was applied to the retempered concrete. This operation was repeated four times to finish the concrete mixture. All the operations took place in a hot environment and with low humidity. The temperature was aimed to be 40 ± 5 Cº and the humidity was aimed to be 20 ± 10% during concreting operation.

The slump and air content of the fresh concretes were determined according to the ASTM C 143 and ASTM C 231 standards, respectively, immediately after mixing [23, 24]. Cylindrical specimens with the dimensions of 4 × 8 in. (10 × 20 cm), were cast for the determination of compressive and splitting tensile strength at various ages. The cylinders were demolded after 24 h and cured in lime-saturated water until the test ages. Compressive and splitting tensile strengths of the hardened concrete samples were determined for 7 and 28 days of age in accordance with ASTM C 39 and ASTM C 496, respectively [25, 26]. In the compressive strength test, the curing temperatures were selected as 23 °C and 50 °C, whereas only a 50 °C curing degree was applied in the splitting tensile strength test.

3 RESULTS AND DISCUSSION

3.1 Properties of Fresh Concrete

3.1.1 Slump value of the Concrete Mixtures

The slump values of the mixtures at the end of 5 minutes, 60 minutes, 120 minutes, 180 minutes and 240 minutes mixing process were given in Fig. 1. At this stage, no retempering operation was applied in order to observe the effect of different SCM inclusion on the slump characteristics of the mixtures. According to the results, it was seen that all mixtures had a 15 cm slump value at the 5 minutes of mixing. With the continuation of the mixing process, the slump value of the control mixture increased to 16 cm at the end of 60 minutes, while the slump values of the mixtures containing 50% FA and 50% BFS remained constant. On the other hand, a slump loss of 1 cm and 15 cm was observed in mixtures containing 50% GCB and 50% NP, respectively. After increasing the mixing time to 120 minutes, the mixture containing 50% FA continued to exhibit a constant slump value, while a slump loss of 3 cm was observed in the control mixture, 12 cm in the mixture containing 50% BFS, and 6 cm in the mixture containing 50% GCB. The slump loss was observed continuously at the mixing times of 180 and 240 minutes, and at the end of 240 minutes, the mixture containing 50% FA showed a slump value of 1 cm, while all other mixtures exhibited zero slump value.

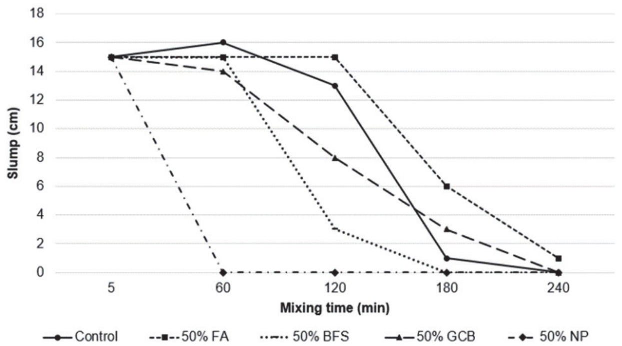

Figure 1 Slump value of the mixtures without retempering operation

According to the results presented in Fig. 1, it was observed that regardless of binder design, all mixtures experienced a slump loss over mixing time due to the evaporation of some water and stiffening of concrete by the start of the hydration process [8, 10]. On the other hand, less slump loss behavior of a mixture containing 50% FA compared to other mixtures can be attributed to the positive effect of fly ash on the fluidity of the mixture as a result of reducing surface friction by creating a ball-bearing effect thanks to the spherical grain structure of the fly ash [27, 28]. Considering the slump values of mixture containing 50% GCB, it can be said that higher water absorption capacity of clay brick caused an improvement in water demand to exhibit same slump value with the control mixture due to angular grain structure and rough surface of clay brick powders as reported in other literature studies [29, 30]. The mixture containing 50% BFS exhibited lower slump values than the control mixture during the entire mixing period. This situation can be attributed to the higher water absorption capacity of finely ground BFS having higher surface area [20]. At last, it was observed that the mixture containing 50% NP exhibited zero slump value at the 60th minute. This situation can be associated with the very high Blaine fineness value of the NP. In this context, it has been reported that cementitious mixtures containing high volumes of natural pozzolans stiff very quickly and the flow value decreases considerably [31]. Also, it can be stated that cement replacement process which proceeded on weight basis led to an increment of the total surface area of materials in the mixture and resulted in a greater slump loss compared to control mixture.

The amount of SP required for the mixtures to reach a slump value of 15 ± 2 cm at all mixing times within the scope of the retempering process was presented in Tab. 4. As a result of retempering with the use of various amounts of SP, obtained slump values of the mixtures were presented in Fig. 2. Results showed that the required amount of SP to achieve the targeted slump value of 15 ± 2 cm was in relationship with the slump values of the mixtures produced without retempering operation. In this context, while 213 g of SP was required for the mixture containing 50% NP with zero slump at 120 minutes, 143 g of SP was found to be sufficient for the mixture containing 50% GCB with a slump of 8 cm. On the other hand, SP was utilized for all mixtures produced within the scope of the study at the end of the mixing period of 180 and 240 minutes, and SP ratio was generally greater for the mixtures with lower slump values. At the end of 240 minutes of mixing, it was observed that the mixture containing 50% FA reached the highest slump value of 16 cm with the use of the least amount of SP among all mixtures, while the highest ratio of SP should be used for the mixture containing 50% NP in order to reach a slump value of 15 cm. As previously stated, the large contribution of FA to workability resulted in a mixture with a greater slump value with reduced SP utilization as compared to other mixes.

Table 4 Required amount of SP for achieving targeted 15±2 cm slump value / g

Mixture	Mixing time / min			
	60	120	180	240
Control	0	0	222	446
50% FA	0	0	296	331
50% BFS	0	147	291	446
50% GCB	0	143	238	437
50% NP	177	213	416	622

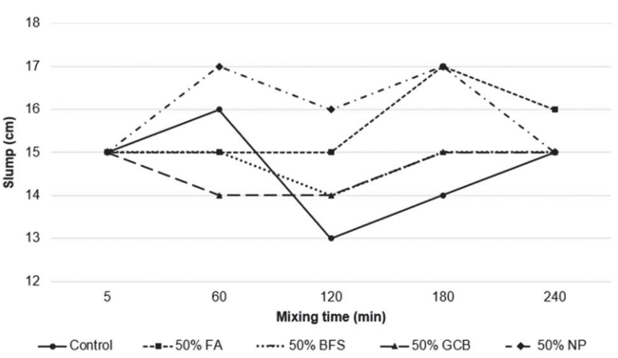

Figure 2 Slump value of the mixtures after retempering operation

Consequently, it was seen that all mixtures reached the targeted slump value of 15 ± 2 cm with the addition of SP. The results proved that slump loss caused by prolonged mixing, hot weather conditions, and worksite delays can be completely eliminated as a consequence of retempering with SP to achieve the desired slump value for casting.

3.1.2 Air Content of Concrete Subjected Prolonged Mixing

The air content of the mixtures after 5, 60, 120, 180 and 240 minutes of mixing were presented in Fig. 3. After mixing for 5 minutes, the air content of the mixtures varied between 6 - 8.5%. Similarities observed in the air content of the mixtures can be mostly attributed to the same slump value of the mixtures since the air content of the mixture is highly dependent on workability. The higher workability provides better dispersion of air bubbles and results in an increment of total air content [32]. In the 60 minutes of the mixing duration, the air content of the mixture containing 50% NP drastically decreased by about 86.7% while the air content of the other four mixtures increased between 17.64 - 62.5%. This behaviour of the mixture containing 50% NP might be attributed to the filler effect of finely ground NP which yields a decrease in the air content of the mixture [33]. On the other hand, significant reductions in the air content of the mixtures were observed at mixing times longer than 60 minutes. In this context, the control mixture exhibited the highest air content reduction among all mixtures by 80.77% from 60 minutes to 240 minutes of mixing time. The air content of the mixture containing 50% FA increased by 4.54% of the mixing time from 60 minutes to 120 minutes and decreased by 76.52% of the mixing time from 120 minutes to 240 minutes. In addition, mixtures containing 50% BFS and 50% GCB showed a 73.3% and 82.2% decrease in total air content, respectively, with mixing time increased from 60 minutes to 240 minutes. Prolonged mixing operation at high ambient temperature yields a higher degree of hydration reactions of cement which can cause deformation of the order of entrained air in concrete, thus the transformation of regularly precipitated entrained air into the entrapped air. As a result, it was expected that the entrained air content will decrease as a result of prolonged mixing, which can be reflected in a decrease in the total air content [34].

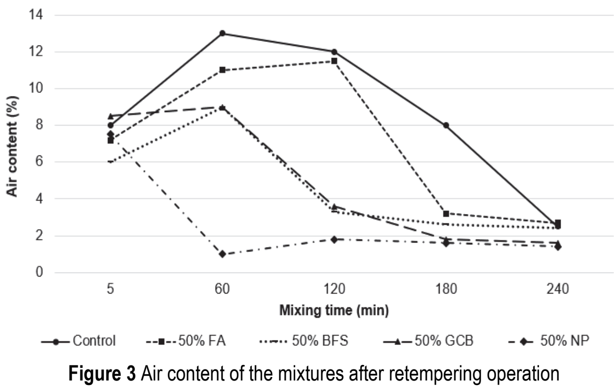

Figure 3 Air content of the mixtures after retempering operation

3.2 Properties of Hardened Concrete

3.2.1 Compressive Strength of the Mixtures

Compressive strength results of the mixtures at the end of 7 and 28 days after 5 minutes, 60 minutes, 120 minutes, 180 minutes and 240 minutes mixing process were given in Fig. 4 and Fig. 5, respectively. According to Fig. 4a, the compressive strength result of the control mixture after 5 minutes of mixing and cured at 23 °C was found to be 28.8 MPa, while the mixture containing 50% BFS exhibited a compressive strength result of 23.9 MPa. On the other hand, compressive strength of the mixtures containing 50% FA, 50% GCB and 50% NP was found to be in the range of 8.4 - 12.7 MPa. It was observed that the compressive strength of the mixtures showed a different trend during the prolonged mixing time. In this context, while the compressive strength of the control mixture tended to decrease at the mixing times of 60 minutes and 120 minutes, it showed the highest compressive strength result at the mixing time of 180 minutes. On the other hand, the compressive strength of the mixture containing 50% BFS increased continuously except for the 180 minutes mixing time, unlike the control mixture. In addition, as a result of the partial hydration of BFS at an early age thanks to its self-cementitious property, it exhibited the highest compressive strength result among all mixtures with 38.2 MPa after 240 minutes of mixing [35]. Mixtures containing 50% FA, 50% GCB and 50% NP showed higher compressive strengths during prolonged mixing (i.e., 120, 180 and 240 minutes). The increase observed in compressive strength in general with the increase in mixing time is most likely related to the decrease in the air content of the mixtures [7]. The reductions observed in the air contents of the mixtures presented in Fig. 3 with increasing mixing time resulted in the mixtures having less pore structure and thus having a denser and more homogeneous matrix. In addition, it can be said that the evaporation of some free water with increasing mixing time may have positively affected the strength of the concrete [17]. Another point to be mentioned is that the retempering process with SP prevented reductions in compressive strength as a result of long-term mixing and even led to improvements in compressive strengths.

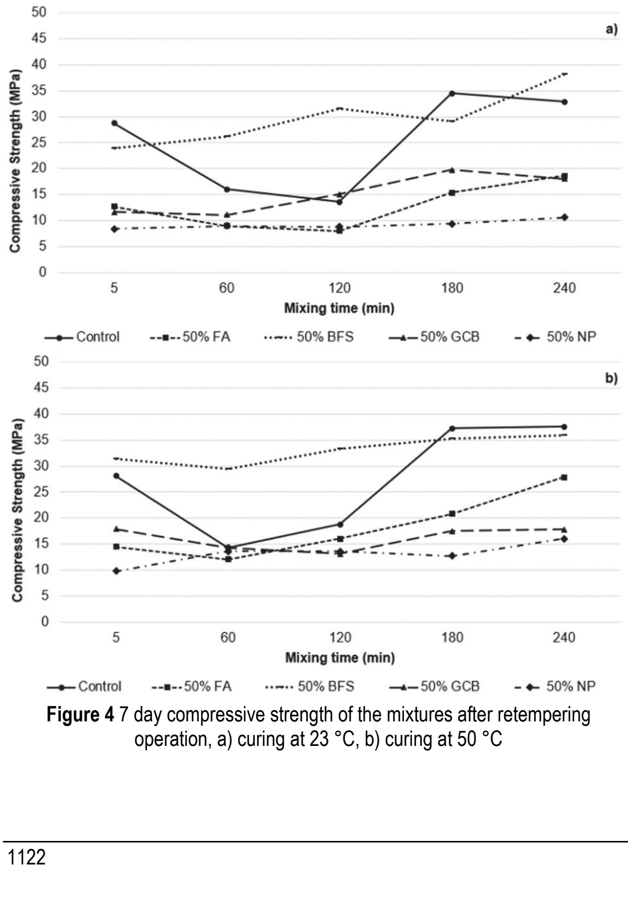

Figure 4 7 day compressive strength of the mixtures after retempering operation, a) curing at 23 °C, b) curing at 50 °C

As a result of the curing process performed at 50 °C, the 7 day compressive strengths of the mixtures were found to have a generally similar trend with the curing at 23 °C. Hot temperature curing, such as 50 °C, considerably increases the evaporation of free water and significantly accelerates the hydration of the cement. As a result, when the compressive strength of all mixtures was taken into account, an increase of 17% was observed in the average compressive strength after the curing temperature increased from 23 °C to 50 °C. The workability losses expected as a result of rapid hardening of the concrete in high-temperature concreting were prevented as a result of retempering with SP, and it was proven by the increase in compressive strengths with increasing mixing time. In addition to this statement, the mixture containing 50% FA exhibited a compressive strength of 18.6 MPa when curing at 23 °C and 27.9 MPa when curing at 50 °C at the end of the mixing period of 240 minutes. This circumstance is also connected to the fact that, as previously noted, the likely loss of workability as a result of hot temperature concreting may be prevented with the using FA thanks to its contribution to workability.

28 day compressive strength results of mixtures cured at 23 °C and curing at 50 °C were given in Fig. 5a and Fig. 5b, respectively. According to the results presented in Fig. 5a, it was observed that the compressive strength of all mixtures increased as a result of increasing the mixing time from 5 minutes to 240 minutes. After 240 minutes of mixing, the mixture containing 50% BFS showed the greatest compressive strength value of 46 MPa in the whole series. It can be stated that in the slag substituted in cementitious composites, pozzolanic property of finely ground BFS provides extra C-S-H/C-A-S-H gel formation to the system, improving the microstructure and thus developing the compressive strength [36]. The compressive strengths of the mixtures containing 50% FA and 50% GCB were found to be similar to the control mixture. On the other hand, the mixture containing 50% NP showed the lowest result with 21.6 MPa compressive strength. This situation is related to the lower mechanical properties of NP blended mixture as a result of its poor pozzolanic activity compared to other mineral admixtures. Although it was not carried out within the scope of this study, it has been reported in various studies in the literature that finely ground NP improves the mechanical properties of the cementitious composite up to a certain substitution ratio, on the other hand, beyond this ratio causes a significant decrease in compressive strength [37, 38].

According to the results presented in Fig. 5b, similar to the 7-day results, it was observed that the average compressive strengths of the mixtures increased by approximately 12.82% as a result of bringing the curing temperature of the mixtures from 23 °C to 50 °C. High curing temperatures are normally predicted to enhance the degree of hydration of the cement, resulting in high compressive strength at an early age and reduced compressive strength at later ages due to the prevention of full hydration as a result of covering the unhydrated cement particles with reaction products. Another factor that causes this situation is the weakening of the workability of the mixture as the high temperature causes the free water to evaporate. However, within the scope of this study, as a result of retempering with SP, the targeted 15±2 cm slump value for each mixture is achieved, thus strength losses due to workability were prevented. In addition, as it is known, the inclusion of finely ground mineral admixtures in the system has a very positive contribution to the mechanical performance at late ages, resulting in an increase in the compressive strength of the mixtures in general. Considering all these factors, it was observed that the retempering process with SP had a positive effect on the compressive strength, and the use of mineral additives showed significant advantages both mechanically and environmentally.

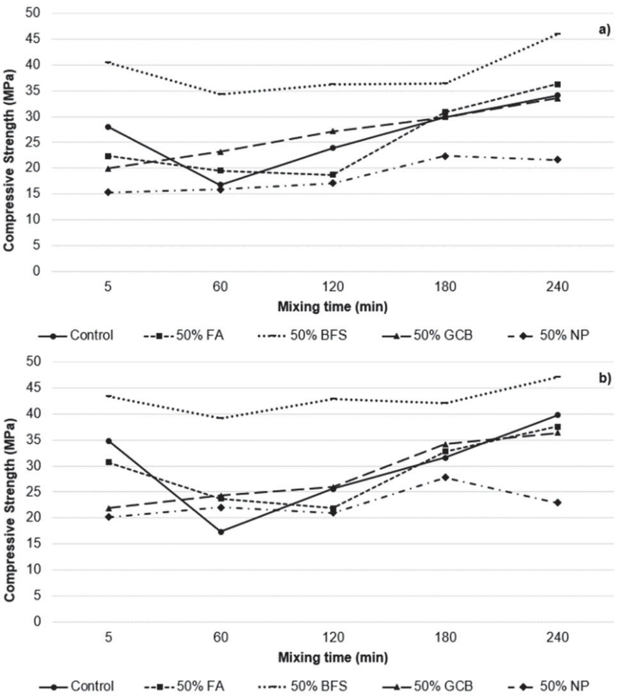

Figure 5 28-day compressive strength of the mixtures after retempering operation, a) curing at 23 °C, b) curing at 50 °C

3.2.2 Splitting Tensile Strength of the Mixtures

The 28 day splitting tensile strength of the mixtures after 5, 60, 120, 180 and 240 minutes of mixing time and curing at 50 °C was presented in Fig. 6. Similar to the compressive strength results, a general increase in splitting tensile strength was observed as a result of prolonged mixing with SP retempering of the mixtures. In this context, when the mixing period was increased from 5 minutes to 240 minutes, the splitting tensile strength of the mixture containing 50% BFS increased by 13.2%, whereas the splitting tensile strength of the control mixture increased by 75%. The increase in splitting tensile strength of the mixtures can be attributed to better compaction of the mixture and providing enough time for aggregates to absorb water as a result of improving workability with the use of SP [21]. On the other hand, no significant change was observed in the splitting tensile strength of the mixtures containing 50% FA, 50% GCB and %50 NP. Also, it should be noted that a decrease in splitting tensile strength was observed in the mixtures containing 50% FA and BFS and control mixture when the mixing time was increased from 5 minutes to 60 minutes. The splitting tensile strength of these mixtures increased beyond the 60 minute mixing period. As seen in the air content results presented in Fig. 3, this behaviour can be attributed to the fact that the air content of these three mixtures increased when the mixing time was increased from 5 minutes to 60 minutes and decreased significantly after 60 minutes.

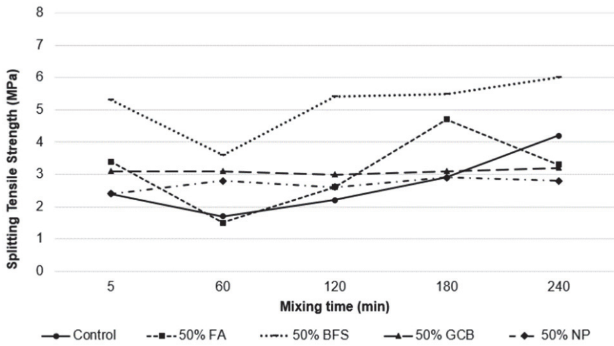

Figure 6 28-day splitting tensile strength of the mixtures after retempering operation after curing at 50 °C

4 CONCLUSIONS

Within the scope of the study, it was focused on the effect of retempering operation with the use of SP on the fresh and hardened properties of concrete mixtures produced with Portland cement and mineral admixtures that were applied in prolonged mixing at hot weather curing. Based on the experimental results, the following conclusions were drawn:

- Mixtures produced without retempering showed a significant decrease in slump values during prolonged mixing. All mixtures, except the one containing 50% FA, reached zero slump value after 240 minutes of mixing. The mixture with 50% FA showed higher slump values due to its positive impact on workability.
- Retempering operation using SP resulted in all mixtures achieving the target 15 ± 2 cm slump value after prolonged mixing. More SP was used in mixtures containing BFS and NP, which have higher Blaine fineness of mineral admixtures. In contrast, the mixture containing FA required a lower ratio of SP to reach the desired slump value.
- With prolonged mixing, significant decreases were observed in the air content of the mixtures, especially beyond the 60 minute mixing period. This was associated with the fact that the entrained air content of the mixtures tended to decrease with the onset of hydration of the cement, thus lowering the total air content.
- Retempering with SP led to an increase in compressive strengths of mixtures during prolonged mixing periods, unlike retempering with water, as it did not alter the water/binder ratio. High temperature curing resulted in higher compressive strengths at both early and late ages, and the use of SP eliminated the loss of workability caused by evaporation of free water during curing. The increase in pozzolanic activity of mineral additives at high temperatures also contributed to the improvement in compressive strength.
- After 240 minutes of mixing, the mixture containing 50% BFS showed the highest compressive strength value of 46 MPa among all mixtures. It can be stated that the high calcium content of finely ground BFS provides extra C-S-H/C-A-S-H gel formation to the system, improving the microstructure and thus developing the compressive

strength. The compressive strengths of the mixtures containing 50% FA and 50% GCB were found to be similar to the control mixture. The mixture containing 50% NP showed the lowest result with 21.6 MPa compressive strength. This situation is attributed to the lower pozzolanic activity of the NP compared to other mineral admixtures.

- A general increase in splitting tensile strength of the mixtures was seen as a result of retempering with SP. The increase in splitting tensile strength of the mixtures can be attributed to better compaction of the mixture and providing enough time for aggregates to absorb water as a result of improving workability with the use of SP. Also, splitting tensile of the mixtures containing 50% FA and BFS and the control mixture was found to be highly related to the air content of the mixtures.

The study showed that the negative effects of prolonged mixing and water retempering on the fresh and hardened properties of concrete can be minimized by using SP for retempering. The research also demonstrated that it is possible to use a high proportion of mineral admixtures without compromising the performance of concrete mixes. FA was found to be the preferred mineral admixture to overcome slump loss problems and provide good strength behavior in hot climates.

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