



Experimental study on the influence of mixing protocol on mortar performance

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Abstract

Mixing is one of the most important processes for producing cement-based materials. Research into the effects of the mixing protocol on the properties of cement-based materials is still in the early stages of development. The effects of various mixing protocols on the fresh and hardened properties of cement mortar in terms of workability, wet density, air content and compressive strength were evaluated. The results showed that the variation in time and speed of mixing influences the properties of cement mortars, both in the fresh and hardened state. Results indicate that the increasing in the mixing time and mixing speed led to reduction of flow values but increases in wet density. Results also indicated that the air content rises with increasing mixing speed but constantly decreased with increased mixing time. Furthermore, compressive strength of each age showed a gradual increase trend with increasing time and speed of the mixing process.

Keywords: Mortar, mixing speed, mixing time, air content, compressive strength

Introduction

The most common building materials used for different aspects of a home building are cement mortar and concrete. The properties of the hardened cement-based materials depend on the selected raw materials and mixing process. The choice of raw materials is the principal role of the engineer based on the features of cement-based materials.

Mixing is a crucial step to achieve desirable homogeneity and performance of paste, mortar or concrete mix by mechanical action through providing enough stress to break up cement agglomerates to help ensure the uniformity of hydration of cementitious materials (Almbrok, 2014) [1].

The degree of homogenisation of the mix achieved in the production of cement-based materials influences their fresh and hardened properties. The mixing quality depends, besides the mixture proportion, essentially on the mixing time, the mixing speed, the geometry of the mixing tool and the mixing sequence (Lowke and Schiessi, 2005) [2].

An appropriate mixing method will lead to better cohesion between particles, generating a smaller number of voids, thus improving the mechanical properties of the final product (Park *et al.*, 2006) [3]. The homogeneity of fresh cement-based materials may affect the internal structure of the final product, which directly affects compressive strength and durability (Zhao *et al.*, 2021) [4]. The extended mixing time plays a crucial role in the ability of the mixture to attain macroscopic and microscopic homogeneity. With limited mixing time, cement particles can only achieve macroscopic homogeneity; and aggregate cannot be completely enveloped by cementitious product (Zhao *et al.*, 2021) [4]. The usual primary requirements of good cement-based materials in its hardened form are satisfactory compressive strength and adequate durability (ACI 304R, 2000; Alazhari and Alshebani, 2013) [5, 6]. The compressive strength and durability of the resulting cement-based materials are greatly depending on its workability for the sufficient compaction (Joshi, 2020) [7].

One of the key success factors for any mixing methods is directly related to the mixing speed, time and mixing sequence (Almbrok, 2014, Hemalatha *et al.*, 2015, Williams

et al., 1999) [1, 8, 9]. Change in these mixing characteristics could alter the properties of fresh and hardened mixtures (Han and Ferron, 2016) [10]. Mixing time and speed are interconnected terms of the energy required to agitate cement-based materials (Joshi, 2020) [7]. Mixing speed can be defined as the speed at which the mixer operates. Mixing time is defined as the time elapsed between the loading of the first constituent to the time of final discharging (Ferraris, 2001) [11].

Various mixing procedures for the preparation of laboratory samples of pastes or mortars (e.g. ASTM 305 and AS 2350.12) [12, 13] are using the Hobart mixer for the mixing process. However, recent practice has recommended the use of higher mixing speed (Han and Ferron, 2016) [10].

Several researchers suggested that the mixing protocol has a significant effect on the fresh properties of the cement-based materials. Trejo and Chen, 2014 [14] stated that increasing mixing speed has adverse effect on cement paste. Their hypothesized based on that when the cement hardens during mixing, the degree of homogeneity decreases. Furthermore, Lowke and Schiessi, 2005 [2] reported that concrete subjected to increase in mixing speed and long mixing time has a reduction in slump value. Dils *et al.*, 2012 [15] concluded that the workability improves with the increase of mixing intensity and time, however slump flow may decrease due to over mixing. In addition, (Dewar and Anderson, 1992) [16] reported that longer mixing time and higher rotation result in increased mixture temperature, increased rate of water evaporation, and increased rate of hydration reactions, as a result, workability decreased. Moreover, the mixing time had no apparent influence on the slump of the concrete whereas, air content and compressive strength increased slightly with increasing mixing time (Dominguez *et al.*, 2019) [17].

The influence of mixing time and higher mixing speed on the hardened characteristics of cement-based materials has also been reported. (Prasittisopin and Trejo, 2014) [18] indicated that increasing mixing time leads to higher 1-day compressive strengths but lower 28-day strengths. Results also showed that an increased mixing speed can result in

increased porosity, leading to decreased strength. (Romano *et al.*,2009) ^[19] evaluated the effect of mixing time on the hardened properties of cement mortar where concluded that the volume of air content increased with increasing mixing time.

In their work, Trejo and Prasittisopin,2016 ^[20] indicated that the hydration reaction of cement paste and mortar has increased with increasing mixing speed and time, producing shorter hardening times. According to Trejo and Chen, 2015 ^[21], extending mixing times has no detrimental effects on the mechanical properties and durability characteristics of the resultant concrete as long as the concrete exhibits adequate workability to be properly cast. Moreover, Ravina and Soroka, 1994 ^[22] stated that there is a positive relation between compressive strength and mixing time. A relationship returns to that prolonged mixing improves homogeneity of mixes and produce a denser product. In addition, Takahashi *et al.*, 2011 ^[23] assessed the effect of mixing time on the microstructure of cementitious materials and reported that the mixtures that were mixed longer have an altered microstructure of hydrated products. Furthermore, Zhao *et al.*, 2021 ^[4] indicated that the durability of concrete can be improved by prolonging the mixing time. Diamond, 2005 ^[24] reported that concrete mixed for longer mixing times can generate smaller fragments from aggregates and smaller cement particles due to impact and friction between the mixer tools and the constituent particles. As a result, the denser transition zone has noticed. Also, Almbrok, 2014 ^[1] cited that with increasing mixing speed, more CSH will be

produced and the resulting microstructure will be much denser.

Changes mixing characteristics, such as speed and time, may change the properties of the fresh and hardened mix. Using or adapting the procedure described in ASTM C305 or other standard test methods generally meets this requirement and can provide reproducibility with reasonable certainty. These standards and guidelines should be adapted to current developments in cement-based materials and technologies to ensure continued added value. Ensuring that existing standards and guidelines add value requires a better understanding of how these mixing variables affect the performance of cement-based materials. Therefore, this research aims to expand the cement mortars knowledge, analyzing the variables influence that composes the mixing process, using different mixing times and mixing speed in the fresh and hardened properties.

Experimental investigation

1. Material

Cement

ASTM type I cement (El-Borge, Zliten (BZ) from Arab Union Contracting Company (AUCC), Libya which meets GPC requirements (ASTM C150, 2016) ^[25] was used to produce the mortars. General purpose cement is preferred because the observation of mortar properties can be done during the normal hydration process, hence the effect of mixing speed and time can be noticed.

Table 1: Percent chemical composition of El-Borge cement analyzed by XRD method

Parameter	Content (%)	
	El-Borge cement	ASTM C150
CaO	62.36	61 – 67
SiO ₂	22.06	19 – 23
Al ₂ O ₃	4.8	2.5 – 6.0
Fe ₂ O ₃	3.68	6 Max
MgO	2.01	5 Max
K ₂ O	0.63	<1.0
SO ₃	2.47	3 Max
Na ₂ O	0.08	<1.0

Fine aggregates

Fine aggregates used were locally available silica sand procured from Awjilah town and called El-Borge sand with an absorption capacity of 0.20%, specific gravity of 2.60.

Prior to use, the fine aggregates were dried in ambient conditions to eliminate any free water. The particle size distribution by sieving method specified in ASTM C 136, 2001 ^[26] is illustrated in Figure 1.

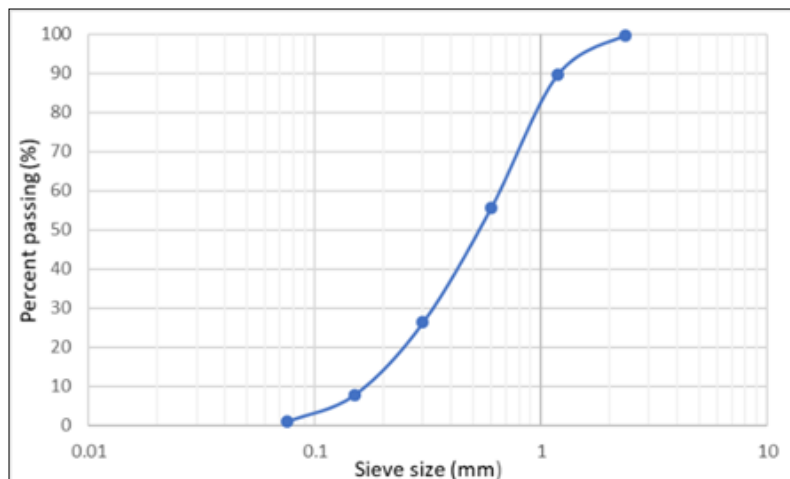


Fig 1: Particle size distributions (Sieving method) of El-Borge sand

Mixing water

Water drinking grade tap water (TW) (pH 7.4; 2.29 μS/cm) was used and conditioned at 22±2 °C prior to use

2. Methods

Mortar composition

The composition of control mortar was in accordance with ASTM C270, 2014 [27] with the mix proportions being 1 part of cement and 3 parts of sand (by mass) at a fixed water/cement ratio (w/c) of 0.50. Each mortar batch comprised cement (450 g), fine aggregate (1350 g), water (225 g).

Mixing scenarios

Mortar mixes were produced using Hobart mixers. The selected mixing speeds considered for the study were 139, 285 and 591 RPM. The parameters of mixing time chosen for each mixing speed are given in Table 2.

Scenario ASTM C305

The water added to the mixing bowl which was securely fastened in place. The cement was then added into the center of the bowl. The Hobart mixer was then turned on a low speed for 30s before the sample of sand was added at a constant rate over the next 30s. At the 60s mark the mixer

was turned up to a high speed and left to mix for 30s. At 90s the Hobart mixer was turned off and the mixing bowl removed in order to scrape down the sides of the bowl to ensure that all raw materials were thoroughly mixed in the middle of the bowl. This action which should be completed within no more than 15s was undertaken using a wetted plastic spatula. The bowl was then covered with a plastic lid and left to sit until the elapsed mixing time reached 180s. At 180s the mixing bowl was once again securely fastened onto the Hobart mixer and turned on to a high speed and left for 60s until the total time reached 240s. At 240s the Hobart mixer was turned off and the mixing bowl removed.

Scenario A - C

In these mixing scenarios, after adding water to the mixing bowl, cement was added to water, stirred for 20s using spatula to a homogenous suspension. Then the sand was charged into the bowl and the Hobart mixer was turned on to the required speed. At halftime of each mixing procedure, the mixer was turned off and the mixing bowl removed in order to scrape down the sides of the bowl within almost 20s before turning the mixer again. After reaching the required time, the mixer was turned off and the mixing bowl removed.

Table 2: Mixing scenarios

Mixing scenario	Sample	RPM	Time (sec)
ASTM	S1	ASTM C305	ASTM C305
A	S2	139	120
	S3		180
	S4		240
	S5		300
	S6		360
B	S7	285	120
	S8		180
	S9		240
	S10		300
	S11		360
C	S12	591	120
	S13		180
	S14		240
	S15		300
	S16		360

Casting and curing

The cement mortar specimens were cast using cubes of (50 mm) from steel molds. The moulds were sealed using zip lock plastic bags to prevent water from evaporating and stored in a moist atmosphere for 24 h using a large plastic box. Demoulding take place after that and thereafter placed in a curing tank filled with water saturated with lime (ASTM C511, 2003) [28] for up to 28 days at a temperature of 22.0 ± 0.5. Water not saturated with calcium hydroxide (high-calcium hydrated lime) may affect test results due to leaching of lime from the test specimens.

Test methods

The fresh mortars were tested for flow (ASTM C1437, 2009) [29], wet density (ASTM C138,2010) [30] and air content (TESTING Bluhm & Feuerherdt GmbH) (ASTM C231, 2010) [31]. Mortar specimens (50 x 50 x 50 mm) were tested at the age of 7 and 28 days for compressive strength. An ADR –Auto V2.0 250/25 compression testing machine

from ELE International, UK was used. The compressive strength was followed the listed procedures of the test method (ASTM C109/C109M, 2013) [32]. Vertical load at a rate of 0.99 kN.s-1 was exerted on the specimens and the maximum load indicated by the testing machine (load at failure) has been recorded. Each value of the results presented in this report is the average of three test samples.

Results and discussion

1. Effect of mixing speed and mixing time on flowability of mortar mixes

As it can see from the Figure 2, the mortar batch mixed using ASTM mixing sequence has lower average flow value than in S2, S3, S7 and S8 mixing scenario and same S12 and S13 mixing scenario.

Generally, the results indicated that the increasing in mixing time and speed led to reduction of flow values. This can be attributed to the increased temperature of mixes and increased rate of water evaporation (Dewar and Anderson,

1992) [16]. The hardening of cement-based materials and reduction their homogeneity could be another factor in reduction workability with the extending mixing time and increase in mixing speed (Trejo and Chen, 2014) [14]. Trejo and Chen, 2015 [21] investigated effects of long mixing time on concrete properties. Their results showed that workability decreased as a function of increasing time. According to Lowke and Schiessl, 2005 [2] increased mixing energy causes more collisions between particles as well as between particles and the mixing tool, so that the agglomerates are more disintegrated. Due to abrasive action, it may also result in further enrichment of fine particles. These activities were accompanied by a continuing increase in surface area, which led to a rise in water demanding. Finally, it leads to a decrease of flowability. Other work showed that lower mixing speed made mixture less workability for long times, exceeding mixing time led to minimize water to cement ratio due to reduction of water content (Abdelmotaal *et al.*, 2020) [33]. As stated by Abdelmotaal *et al.*, 2020 [34], workability decreases with time due to cement hydration and a decrease in mixing water. This reduction in water can be attributed to evaporation. As a result, the friction between the solid particles (cement and aggregates) increased and therefore, the fluidity of the mix minimized. The reduction in workability of cement-based materials due to variations in mixing scenario is a similar to other studies reported in literature (Lowke and Schiessl, 2005, Trejo and Chen, 2014, Dewar and Anderson, 1992) [2, 14-16].

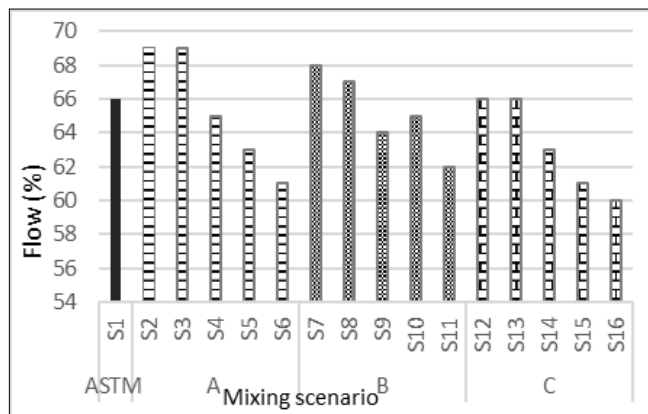


Fig 2: Effect of mixing scenario on flow of mortar mixes

2. Effect of mixing speed and mixing time on wet density of mortar mixes

As seen in Figure 3, the mortar batch mixed using ASTM mixing sequence has higher average wet density than other mixing scenarios. However, on the other hand, it could be seen that the density increases with increasing mixing time for all mixing scenarios.

As demonstrated by Relis and Soroka, 1977 [35], the density of cement increased with the increase in the degree of hydration due to the rise in hydration products. They demonstrated that the hydration process occurring in a confined space, is associated with pressure build-up and as a result, produces denser products. Zichen *et al.*, 2023 [36] mentioned that the accelerated hydration of cement-based materials caused by the increased mixing speed. Furthermore, Han and Ferron, 2016 [37] showed that as the mixing speed increased, cement hydration was accelerated.

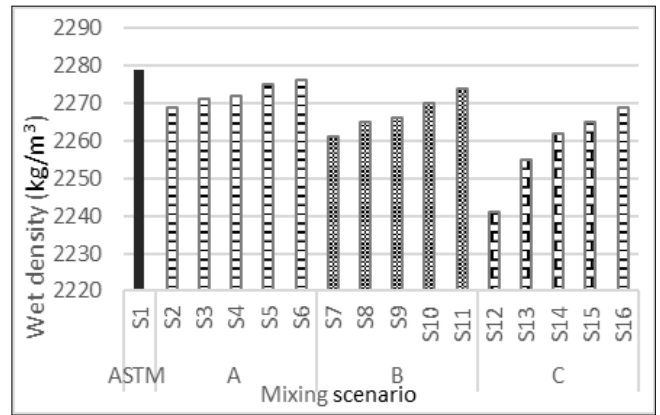


Fig 3: Effect of mixing scenario on wet density of mortar mixes

3. Effect of mixing speed and mixing time on air content of mortar mixes

A trend has been observed in the difference the air content presented in mortar according to the type of mixing scenario (Figure 4)

In mortar mixing using ASTM mixing sequence has lower average air content when compared to the other mixing scenarios. The trend of the increase in the air content of mortar in increasing mixing speed was also observed.

Air voids induction occurs more quickly and air content rises higher as agitation intensity increases (Jia, 2017, Wang and Feng, 2007) [38, 39]. Fukui *et al.*, 2018 [40] cited that cement mortar prepared using high mixing speed had a higher percentage of air content when compared to lower mixing speed.

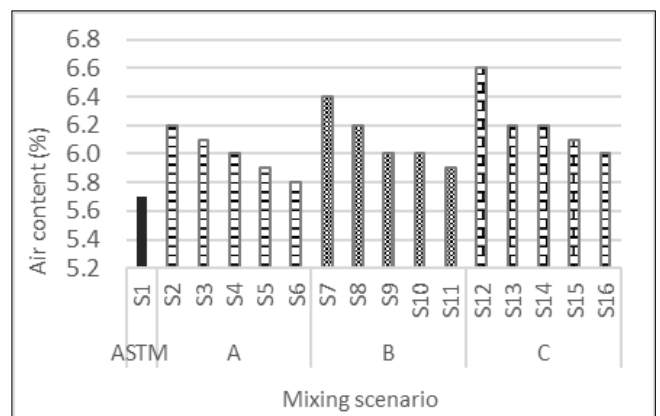


Fig 4: Effect of mixing scenario on air content of mortar mixes

The results also reveal that the time variation promoted inconsiderable change in incorporates air content. Air content constantly decreased with increased mixing time. Zeng *et al.*, 2020 [41] mentioned that the air content of fresh cement-based materials decreases when mixing time is prolonged.

The reason for decreasing air content with prolonging the mixing time could be due to the increase in fineness during the mixing process. Due to collision and friction between the mixer tools and the constituent particles during the mixing process, mortar mixed for extended periods of time can produce smaller fragment aggregates and finer cement particles (Diamond, 2005) [24]. Malisch, 2018 [42] indicated that as finesse of cement-based materials increases, air content decreases.

The trend of the decrease in the air content of mortar, with increasing mixing time, quite matches with the reduction in flow values. The possible explanation for this phenomenon is due to increasing the temperature of mixes. The increase of temperature will lead to decline in air content and workability of concrete (Dewar and Anderson, 1992, Dhakal *et al.*, 2018) [16, 43]. However, more research is needed to fully understand the phenomenon of declination air content with the decreasing in workability.

4. Effect of mixing speed and time on compressive strength of mortar mixes

Variation in mixing time and mixing speed can result in altered compressive strengths at 7 and 28 days (Figure 5 and 6).

Compressive strength values at 7 and 28 days for mortar mixed following ASTM method showed higher results when compared with other mixing scenarios. The reason for that is because the mortar produced by ASTM method has a lower air content value as compared to the others. The compressive strength is adversely affected by the ratio of air content in compacted mortar where increased air content reduces compressive strength (Mazloom and Ranjbar,2010, Aljabri, 2022) [44, 45].

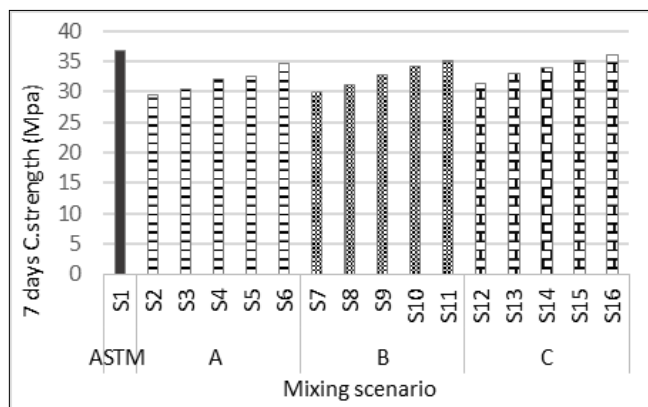


Fig 5: Effect of mixing scenario on 7 days’ compressive strength of mortar mixes

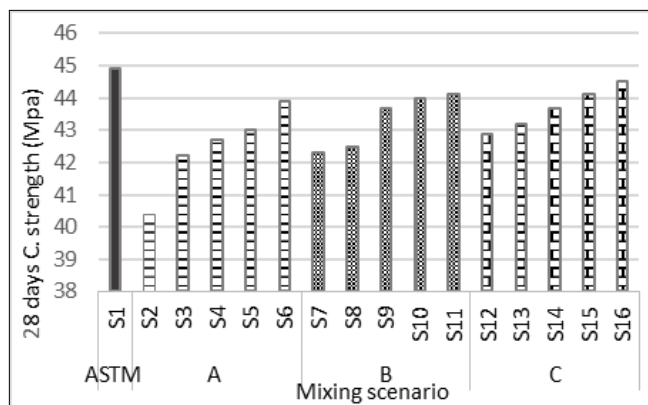


Fig 6: Effect of mixing scenario on 28 days’ compressive strength of mortar mixes

With the increase of mixing time and mixing speed, the compressive strength of each age shows a gradual increase trend. This improvement of compressive strength as a function of increasing mixing time and mixing speed can be due to the results of the grinding effect of cement particles with increasing mixing speed and prolonging mixing time.

This lead to get finer cement, hydration enhanced and therefore, the resulting strength had developed (Abdelmotaal *et al.*, 2020 and Kirca *et al.*, 2002) [34, 46]. Furthermore, Abdelmotaal *et al.*, 2020 and Kirca *et al.*, 2002 [34, 46] refereed that the loss of water due to evaporation lead to decrease w/c ratio and as a result, more compressive strength obtained. Also Han and Ferron, 2016 [47] showed that the compressive strength of cement-based materials increased with exceeding mixing time as a result of hardening and stiffening.

Conclusion

This study assessed the influence the extended mixing time and increased mixing speed on the performance parameters of cement –based materials. At various mixing period and mixing speed, the fresh and hardened characteristics of cement mortars in terms of workability, wet density, air content and compressive strength were examined. The finding suggested that the increasing in mixing time and mixing speed affected adversely flowability of mortar and increased the wet density. The air content rises with increasing mixing speed but constantly decreased with increased mixing time. The compressive strength of each age showed a gradual increase trend with increasing time and speed of mixing.

References

1. Almbrok MH. Cement-based stabilisation/solidification of oil and salt contaminated materials, in Civil and Environmental Engineering. University of Technology, Sydney (UTS), 2014.
2. Lowke D, Schiessl P. Effect of mixing energy on fresh properties of SCC, in 4th International RILEM Symposium on self-compacting concrete. Chicago, USA, 2005.
3. Park KB, Plawsky JL, Littman H, Paccione JD. Mortar properties obtained by dry premixing of cementitious materials and sand in a spout-fluid bed mixer Cement and Concrete Research,2006:36:728-734.
4. Zhao W, Yang J, Zhaow W, Yang C. Experimental study on the influence of mixing time on concrete performance under different mixing mode. Science and Engineering of Composite Materials,2021:28:638-651.
5. ACI 304R, Guide for measuring, mixing, transporting, and placing concrete. American Concrete Institute, 2000.
6. Alazhari MS, Alshebani MM. "Assessment of concrete quality in Libya" Nestmann F, Schlangen E and Asad S (eds). Proceeding of the 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering, Procedia Engineering, Sebelas Maret University, Indonesia, 2013, 17-126.
7. Joshi BR. Effect of mixing speed and time on fresh properties of cement mortar. Global Scientific Journal, 2020, 8(2).
8. Hemalatha T, Sundar KR, Lyer NR. Influence of mixing protocol on fresh and hardened properties of self-compacting concrete. Construction and Building Materials,2015:98:119-127.
9. Williams DA, Saak AW, Jenning HM. The influence of mixing on the rheology of fresh cement paste. Cement and Concrete Research,1999:29:1491-1496.
10. Han D, Ferron R. Influence of high mixing intensity on rheology, hydration, and microstructure of fresh state

- cement paste. Cement and Concrete Research,2016:84:95-106.
11. Ferraris CF. Concrete mixing methods and concrete mixers: State of art. Journal of Research of the National Institute of Standards and Technology, 2001, 106(2).
 12. ASTM C305. Standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency. American Society for Testing and Materials (ASTM), USA, 2014.
 13. AS 2350.12. Methods of testing Portland, blended and masonry cements method 12: Preparation of a standard mortar and moulding of specimens. Standards Australia International Ltd, 2006.
 14. Trejo D, Chen J. Effect of extended discharge time and revolution counts for ready-mixed concrete. The Kiewit Centre for Infrastructure and Transportation: Oregon State University, 2014.
 15. Dils J, DeSchutter G, Boe V. Influence of mixing procedure and mixer type on fresh and hardened properties of concrete: a review. Materials and Structures,2012:45:1673-1683.
 16. Dewar JD, Anderson R. Manual of ready mixed concrete. Vol. second edition. Glasgow, UK: Blackie Academic and Professional, 1992.
 17. Domínguez JA, Jiménez LA, Muñoz JF. Influence of mixing time on fresh and hardened cast-in-place Concrete. Journal of Engineering Research and Reports,2019:6(2):1-6.
 18. Prasittisopin L, Trejo D. Effects of mixing variables on hardened characteristics of Portland cement mortars. ACI Materials Journal,2014:111:1-6
 19. Romano RC, Schreurs H, Silva FB, Cardoso FA, Barros FA, *et al.* Impact of the mixer and time of mixing on the properties of industrialized mortar. Ambiente Construído,2009:9(4):109-118.
 20. Trejo D, Prasittisopin L. Effects of mixing variables on early-age characteristics of Portland cement systems. Journal of Materials in Civil Engineering, 2016, 28(10).
 21. Trejo D, Chen J. Influence of mixing time on fresh and hardened concrete characteristics. ACI Materials Journal,2015:12(6):745-753.
 22. Ravina D, Soroka I. Slump loss and compressive strength of concrete made with WRR and HRWR admixtures and subjected to prolonged mixing. Cement and Concrete Research,1994:24(8):1455-1462.
 23. Takahashi K, Bier TA, Westphal T. Effects of mixing energy on technological properties and hydration kinetics of grouting mortars. Concrete Research,2011:41(11):1167-1176.
 24. Diamond S. The patch microstructure in concrete: Effect of mixing time. Cement and Concrete Research,2005:35(5):1014-1016.
 25. ASTM C150/C150M, Standard specification for Portland Cement. American Society for Testing and Materials (ASTM), USA, 2016.
 26. ASTM C136, Standard test method for sieve analysis of fine and coarse aggregates. American Society for Testing and Materials (ASTM), USA, 2001.
 27. ASTM C270, Standard specification for mortar for unit masonry. American Society for Testing and Materials (ASTM), USA, 2014.
 28. ASTM C511, Standard specification for mixing rooms, moist cabinets, moist rooms, and water storage tanks used in the testing of hydraulic cements and concrete. American Society for Testing and Materials (ASTM), USA, 2003.
 29. ASTM C1437, Standard test method for flow of hydraulic cement mortar. American Society for Testing and Materials (ASTM), USA, 2009.
 30. ASTM C138, Standard test method for density (Unit weight), yield and air content (Gravimetric) of concrete. American Society for Testing and Materials (ASTM), USA, 2010.
 31. ASTM C231, Standard test method for air content of freshly mixed concrete by the pressure method. American Society for Testing and Materials (ASTM), USA, 2010.
 32. ASTM C109/C109M, Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens). American Society for Testing and Materials (ASTM), USA, 2013.
 33. Abdelmotaal A, Abdelreheem A, and Mahdy M. Effect of low mixing speed on the properties of prolonged mixed concrete. Civil Engineering Journal,2020:6(8):1581-1592.
 34. Abdelmotaal AM, Abdelraheem AH, Mahdy MG. Effect of time and speed mixes on concrete properties. International Journal of Engineering and Innovative Technology (IJEIT), 2020, 9(9).
 35. Relis M, Soroka I. Variation in density of Portland cement hydration products. Cement and Concrete Research, 1977, 7(66).
 36. Zichen L, Xinyi P, Zhiwei L, Zhenping S, Dietmar S. Influence of mixing speed on the hydration and setting performance of cement paste in the presence of triethanolamine. Construction and Building Materials, 2023, 385.
 37. Han D, Ferron R. Influence of high mixing intensity on rheology, hydration, and microstructure of fresh state cement paste. Cement and Concrete Research,2016:84:95-106.
 38. Jia D. Control of bubble introduction in ultra-high performance concrete mixing and its effect on strength. MSC, Harbin Institute of Technology, Harbin, China, 2017.
 39. Wang WZ, Feng ZX. Analysis of the effect of mixing speed on the air content of freshly mixed concrete. Concrete, 2007:8:83-88.
 40. Fukui E, Martins EJ, Campos HF, Pinto MC, Silva SH, *et al.* The influence of mixing procedure on fresh behavior of industrialized coating mortar and on site produced mortar. Materia-Rio de Janeiro, 2018, 23.
 41. Zeng X, Lan X, Zhu H, Liu H, Umar HA, *et al.* A review on bubble stability in fresh concrete: Mechanisms and main factors. Materials,2020:13(8):1820-1843.
 42. Malisch W. Concrete construction article. The trouble with bubbles, 2018.
 43. Dhakal H, Bourmaud A, Berzin F, Zhang Z, Shah D, Beaugrand. Mechanical properties of leaf sheath date palm fibre waste biomass reinforced polycaprolactone (PCL) biocomposites. Industrial Corps and Products,2018:126:394-402.
 44. Mazloom M, Ranjbar A. Relation between the workability and strength of selfcompacting concrete. in 35th Conference on our world in concrete and structures. Singapore, 2010.

45. Aljabri M. Concrete porosity and transport processes, in integral waterproofing of concrete structure. Woodhead, 2022, 37-68.
46. Kirca O, Turani L, Erdogan T. Effect of retempering on consistency and compressive strength of concrete subjected to prolonged mixing. Cement and Concrete Research, 2002;32(3):441-445.
47. Han D, Ferron R. Effect of mixing speed on rheology of superplastized Portland cement and limestone powder pastes. ACI Materials Journal, 2016, 114(4).