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Mixing Efficiency of Energy Saving Gravity Mixer (ESG Mixer) for High Slump Concrete

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Abstract

M-Y mixer, in its horizontal set-up, was made possible to mix lightweight and viscous materials in the real site. The mixing mechanism was modified for its use in vertical set-up. It was renamed Energy Saving Gravity mixer (ESG mixer) for its mixing efficiency under the gravity. Slump and air content of both high slump concretes mixed in the ESG mixer were less than those from the conventional mixer. However, compressive strengths were obtained more in the ESG mixer. The decrease in slump and air content values was due to the transportation and elapsed time of the pre-mixed mortar. It is concluded that the ESG mixer has sufficient efficiency for mixing the high slump concrete continuously. The loss in slump and air content can be minimized by developing the high productivity continuous concrete production system reducing elapsed time. The achieved result is applied in two dam construction sites.

Keywords: M-Y mixer; Mixing mechanism; High slump concrete; ESG mixer; Continuous concrete Production system

Introduction

Concrete is the mixture of cement, water, fine and coarse aggregates which are batched in certain proportion and mixed in the concrete mixers to meet its desired properties. Mineral and chemical admixtures are also added to enhance the required properties [1]. The primary required properties of concrete are that it should give the designed compressive strength and an adequate durability. For it, the fresh concrete should be cohesive enough for the methods of transportation from the mixer (batching plant) and placing used without having any segregation with a consequent lack of homogeneity of the finished product [2].

Proper mixing of concrete requires the uniform distribution of its any ingredient without segregation and well coating of finer particles around the coarser particles. It means powder materials should well be coated by water followed by fine aggregates by paste and then coarse aggregates by mortar. In mixing of concrete, electrical energy supplied to the mixer is changed to the mechanical energy and it rotates the mixer (or shafts/blades/screws inside the mixer) which agitates the ingredients. This process continues until the desired quality of fresh concrete is achieved. The sufficient mixing of concrete requires that the difference on mass of unit volume of mortar and the content of coarse aggregate should be less than 0.8% and 5% respectively [3]. The properties of concrete differ not only by the mixing time but also by the type of mixer used, the same properties of concrete cannot be obtained at the same mixing time even when the mix proportion is the same. It is because the condition to obtain the same properties of concrete using different type of mixer is to mix the concrete with the same energy consumption of the mixer measured by means of electricity [4].

There are mainly 2 categories of mixer as batch type mixers and continuous mixers. The batch type mixer produces one batch of concrete at a time. The batch hereby refers the volume of concrete to be mixed in the batch type mixer at a time. After the full completion of mixing and the discharging, then the ingredients of second batch are charged into the mixer for mixing. Continuous mixers are those in which feeding of concrete ingredients, mixing and discharging of mixed concrete are carried out in the continuous way [5].

Depending upon mixing criteria, mixers again can broadly be divided into two major classes as free fall and forced action types. Generally, drum type mixers (tilting and non-tilting types) fall into free fall type and others like pan mixers, shaft mixers (single and double shafts) as well as continuous mixers fall into forced action types. However, the mixing efficiency of even similar type of mixers may differ in the design method of different manufacturers. But it should be considered that the energy consumption per given time in forced action categories is more than that in free fall categories. It has been claimed that very high intensity mixing can result in better workability and higher strength concrete [6].

The concept of "mixer efficiency" is used to qualify how well a mixer can produce a uniform concrete from its constituents. RILEM defines that a mixer is efficient "if it distributes all the constituents uniformly in the container without favoring one or the other". Therefore, in evaluating mixer efficiency, properties such as segregation and aggregate grading throughout the mixture should be monitored [7]. Screw type continuous mixers are considered as less efficient. Such mixers are only used for applications that require a short working time, long unloading time, remote sites (not suitable for ready-mix) and/or small deliveries [8]. Since such mixers are used for low slump (non-flowable) concretes (e.g., pavements), they may not be fit to mix high slump concrete continuously which can be used in buildings and civil structures.

The new 2n mixing theory was developed with the concept of the Japanese noodles (udon) mixing method. It is based upon kneading and lapping mechanism that with n numbers of kneading and lapping process, 2n layers of material are formed resulting in uniform distribution of each ingredient [9]. With the development of one proto-type experimental mixer, it was verified that the use of this theory was possible to mix concrete materials giving similar quality of concrete in fresh as well as in the hardened state [10]. Moreover, light weight concrete using Expanded Polystyrene (EPS) beads were also possible to develop using this mixing method [11].

A continuous mixer, M-Y mixer (previously named as MY-BOX), was developed to use it for mixing the materials in real site [12]. The horizontal setup of M-Y mixer system was used in the real construction sites to mix the dredging sludge with cement paste for the ground settlement [13]. Moreover, this system was also made possible to mix lightened dredging sludge (with use of EPS beads) with cement paste in the real sites [14]. However, the horizontal setup of M-Y mixer, based on kneading and lapping mechanism, was completely failed to mix large size particles, like concrete. In order to make the possible to mix the workable concrete in the vertical set up of M-Y mixer, the basic concept of mixing mechanism of the inter-particle collisions and impact was developed. It was then applied to the vertical set-up of M-Y mixer with inclusion of splitting and recombining actions [15]. The basic concept of new mixing mechanism and its application in vertical set of M-Y mixer are shown in Figures 1& 2 respectively.

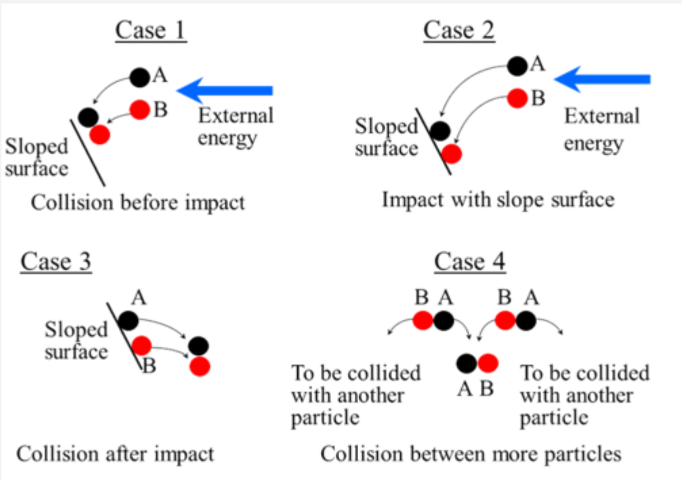

Figure 1: Concept of New Mixing Mechanism.

With use of five units of model M-Y mixer (opening size of 20mm by 20mm, slope of 63°, connected in vertical set-up), the developed mechanism was verified for mixing efficiency. In order to represent such new mixing mechanism without use of any external energy for mixing, the vertical set-up of M-Y mixer was proposed to term as Energy Saving Gravity mixer (ESG mixer) [15]. It is shown in Figure 3.

The modified mechanism resulted in the reduction of the external energy to be required for mixing, since materials could be mixed when falling inside ESG mixer under gravity force only. Different types of very low slump concrete like RCD and dam concrete were mixed at real dam construction site resulting in similar properties with that of conventional method [16,17]. Moreover, ESG mixer has gained its category as High-Performance Mixer (HPM) class over all from its comprehensive assessment by carrying out all tests compiled with the highest requirement specified by RILEM TC 150 [18].

New method of mixing procedure, called "Pre-mix" method was developed, in which fibers were first mixed with dry aggregates (coarse aggregate and also fine when necessary) in ESG mixer to obtain the dry mix of fibers and aggregates. Then, mixing of SFRC was carried out by mixing pre-mix with mortar in ESG mixer. With this developed method, content of fiber was able to be increased with achievement of good result as required [19].

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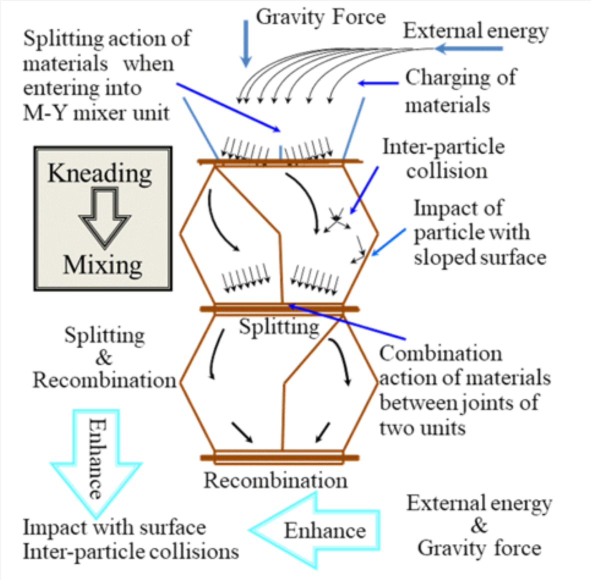

Figure 2: Development of New Mixing Mechanism in M-Y Mixer.

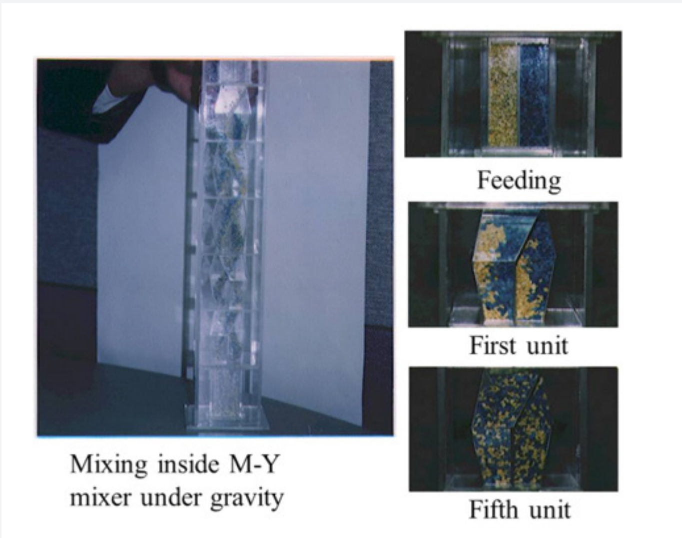

Figure 3: Preliminary Mixing Experiments in Vertical Set-up of M-Y Mixer.

More interestingly, two different powder materials were made possible to be mixed in ESG mixer with very low variation coefficients on distribution of two different powder materials [20]. However, the efficiency of ESG mixer was not checked yet for the high slump concrete mostly used in building and civil structures. The main aim of this research work was to investigate the efficiency of the modified mixing mechanism, in vertical set up of M-Y mixer, for the high slump concrete to be used in building and civil structures.

Experimental Procedures

Since pre-mixed mortar is used to mix concrete in ESG mixer, its mixing process was regarded as double mixing which has also been applied in conventional mixing. The required amount of mortar was mixed in the conventional double axis forced action mixer. The model of the ESG mixer set-up for mixing high slump concrete is shown in Figure 4. The set-up of ESG mixer is mainly composed of ESG mixer units, conveyor-belt, charging hoppers, buckets and supporting accessories (scaffolding, not shown in the figure). The data are shown in the figure for the reference which was used for the experiment work (all in mm except mentioned).

Six numbers of ESG mixer units were connected vertically. Each unit has its opening size of 270mm×270mm and surface slope of 63°. The commercially available conveyor-belt was modified with respect to its inner allowable cross-sectional area and speed to control the supply rate. The charging hopper was connected with the upper most inlet of the first unit of ESG

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mixer. Its main function was to avoid the loss of any materials when feeding into the ESG mixer in continuous way. Its slope and its height difference with the conveyor belt should make the notable effect on the flowing criteria of materials on entering into the ESG mixer. The most noted effect should be with the downward speed, inter-particle collision and impact.

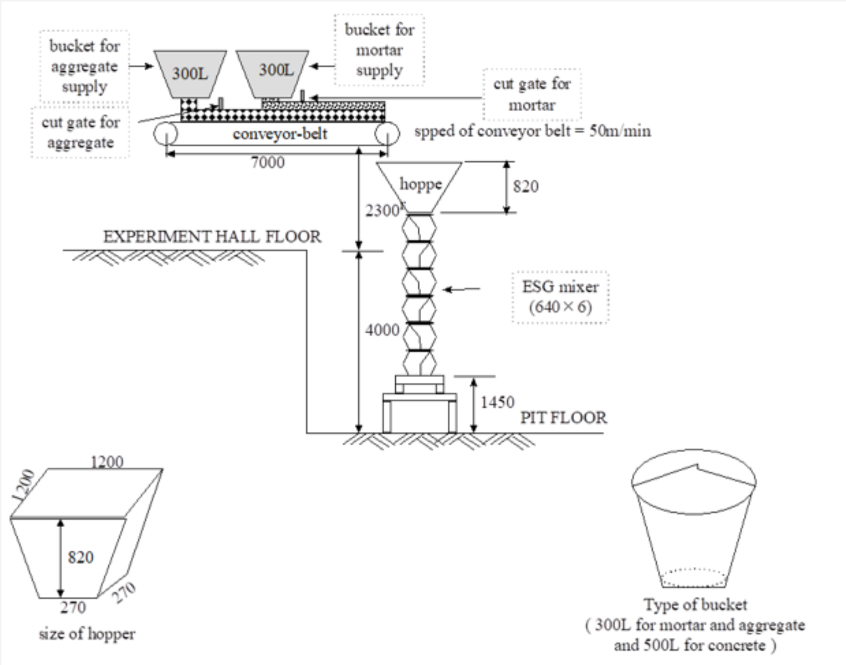

Figure 4: Experimental Set-up for Mixing High Workable Concrete (Cut-Gate Method).

Two buckets were used to supply pre-mixed mortar and coarse aggregates to the conveyor-belt while feeding to ESG mixer. Another bucket was used to collect the mixed concrete discharged from the ESG mixer. The capacity of each buckets was designed depending upon the type of concrete and its volume in one series of continuous mixing. In order to control the supply rate of aggregate and mortar; cut-gates were used on the conveyor-belt. Cut-gate method was considered as an appropriate and economical method to control the supply rate of aggregate and pre-mixed mortar for this preliminary experimental work. The opening size of cut-gates for both coarse aggregate and pre-mixed mortar was pre-designed with all possible affecting factors. Then, it was fixed with numerous pre-trial calibration tests for the designed mix proportion of concrete to be used in this experiment.

Concrete mixing procedure using ESG mixer is quite different with that in the conventional batch type mixers in the sense of material preparation and feeding process. ESG mixer was continuous mixer in which feeding of concrete ingredients, mixing and discharging of the concrete should be done in the simultaneous way. In order to judge out the mixing efficiency of ESG mixer for the high slump concrete in experiment level, mixing was carried out with the determined volume of concrete in one series of continuous mixing.

All the required materials of concrete, i.e. cement, sand, coarse aggregates, water and chemical admixtures were prepared, and their quality were maintained according to the requirements as mentioned in Japan Industrial Standards (JIS). The quality of the cement was maintained according to the requirement mentioned in JIS R 5210-1992 [21]. Surface of the coarse aggregates were maintained with saturated surface dry condition. The water content by the finer aggregates were determined by the moisture content test based on JIS A 1111-1976 [22] and it was adjusted with total unit water content in the mix for calculating the water amount to be added to the designed concrete mix.

Pre-mix mortar was mixed in the double axis forced type mixer. Before mixing the actual mix of the mortar to be used for mixing in the ESG mixer, the initial batch of the mixed mortar was used for buttering the mixer and other equipment like buckets (small and big), conveyor-belt and ESG mixer as well. The quality control of the mortar was judged with its temperature, table flow test and visual check as well. The amount of mortar to be used per one mix was decided by weight batching. The required amount of mortar was poured to the mortar bucket and it was transferred to the position of mortar cut gate on conveyor belt.

The amount of coarse aggregates to be used in one mixing was batched by weighing and poured into the aggregate bucket and it was transferred to the position of aggregates cut-gate on conveyor-belt. Supplying of materials for mixing was carried out mainly in two ways as continuous supply method (cut-gate method) and layering method. Cut-gate method was used for AE

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15 concrete and layering method for AE 8 concrete. In cut-gate method, coarse aggregates were first poured on the conveyor-belt and brought, through the cut-gate of coarse aggregates, to the position of the mortar cut-gate by running the conveyor-belt. Then, the mortar was poured to the above of aggregates and these two phases were continuously poured into the ESG mixer until finish. Precaution was taken while pouring the mortar on the top of aggregate that the mortar should be covered uniformly through the width and should not be overflow from any side. 300 liter of concrete was mixed at one time of mixing.

In layering method, only 100 liter of concrete was used for one mixing. Coarse aggregates were first layered uniformly throughout the length of the conveyor belt. Then, pre-mixed mortar was uniformly distributed on the top of coarse aggregates. The length and the depth of the layer of coarse aggregate and mortar was pre-designed and checked while layering. The discharged concrete from the outlet of ESG mixer was collected into the bucket. After finishing of mixing, the bucket containing mixed concrete was shifted to the testing area by portable crane. Concrete was poured to three positions on floor by maintaining the first and last portion of about 50 liter and the middle portion of 200 liter. The special care was made when pouring concrete from the bucket to avoid the segregation. The middle 200liter concrete was taken for the tests. The visual check was focused to justify the quality level of concrete that mixed in ESG mixer with regard to the distribution condition of two different phases and the coating condition of one phase (coarse aggregates) with that of another phase (mortar). Slump test and air content test were carried out according to JIS A 1101-1976 [23] and JIS A 1118-1976 [24] respectively. The specimens for 7 days and 28 days compressive strength tests were prepared and cured according to the method as specified on JIS A 1132-1993 [25] and their respective tests were carried out as according to JIS A 1108 [26].

For all different types of test results, the comparison was made with those from the conventional method.

For the second method of supplying, i.e. layering method, the mixing method was similar to first one except sampling and test method. The whole amount of concrete was used for sampling and tests.

Test Results and Discussions

In order to carry out the mixing work of ESG mixer for high slump concrete, two standard mix proportions were chosen, one to be used for building engineering and another for the civil engineering structures. Mix proportions of two types concrete are given in Table 1. In the table, the first mix proportion of concrete with maximum aggregates size of 20 mm (i.e. Gmax = 20mm) is AE 8 concrete and the second with Gmax = 40mm is AE 15 concrete.

Table 1: Mix Proportion of Concrete.

Mix Condition					Unit Content (kg/m^3)				
G_{max} (mm)	Slump (cm)	Air (%)	W/C (%)	S/a (%)	Water W	Cement C	Sand S	Gravel G	Admixture No.70
20	15	4.5	55	45	177	322	803	1010	0.81
40	8	4.5	55	45	165	300	822	1039	0.75
G_{max}: Maximum aggregate size, S/a: Sand to total aggregate ratio									

Visual condition of the concrete mixed in ESG mixer was found with the similar quality to that from the conventional mixing. Test results of AE 8 and AE 15 concretes are shown in Tables 2 & 3 respectively. It should be noted that the Table 2 corresponds with the data of concrete mixed using layering method; whereas Table 3 is that by continuous supplying of materials using cut-gate method.

Table 2: Test Results of AE 8 Concrete.

Mixer Type	Concrete Temperature (°C)	Slump (cm)	Air (%)	Compressive Strength			
				Average (MPa)		Variation Coeffs. (%)	
				7 days	28 days	7 days	28 days
Forced	14.5	9.5	5.8	20.5	24.9	0.8	2.1
ESG mixer	12	5.6	3.6	22.5	29.1	3.5	3.2

Table 3: Test Results of AE 15 Concrete.

Mixer Type	Concrete Temperature (°C)	Slump (cm)	sAir (%)	Compressive Strength			
				Average (MPa)		Variation Coeffs. (%)	
				7 days	28 days	7 days	28 days
Forced	19	15.5	5.5	30.5	37.3	1	3.6
ESG mixer	20	13.5	3.6	30.9	39.5	3.6	3.9

Table 2 shows that the slump of concrete mixed in ESG mixer (5.6cm) is less than that of the conventional method (9.5cm). It was due to the elapsed time of mortar consumed on the layering process of pre-mixed mortar and coarse aggregates on the conveyor-belt before charging into the ESG mixer. The time period required from the time of mortar mixing to the time of

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concrete discharged from the ESG mixer, in this method, was about 1.5 hour. In order to verify this result, the effect of elapsed time on workability of concrete is shown in Table 4. The concrete of its slump of 16.5cm was decreased to 11.0cm in one-hour elapsed time. And, the slump value of the concrete mixed in the ESG mixer, with the mortar of its elapsed time of 1.5 hour after mixing, was 10.0cm. This result backs up the situation of slump loss noted in the Table 2.

Table 4: Effect of Elapsed Time on Workability of Concrete.

Mixer Type	Elapsed Time after Mixing (mins.)	Concrete temp. (°C)	Slump (cm)	Air Content (%)
Forced	0	20	16.5	5.1
	60	20	11	3.9
ESG mixer	90	20	10	3.6

Air content value of the concrete mixed in the ESG mixer (3.6%) was less than that mixed in the conventional mixer (5.8%). Its reason was the effect of the double stage of mixing. Because, the mortar was first mixed in the conventional mixer, transported and then it was again mixed with coarse aggregates in the ESG mixer. Typically, 1%-2% of air content is usually lost during normal transport (more in hot weather, less in cold weather) [27]. The compressive strengths of concrete mixed in the ESG mixer (7 days: 22.5 MPa; 28 days: 29.1 MPa) were more than those of the conventional method (7 days: 20.5 MPa; 28 days: 24.9 MPa). It should be the reason of 1.5 hour of the elapsed time causing the decrease in slump value as well as air content.

Table 3 summarizes the properties of AE 15 concrete mixed in ESG mixer, in which pre-mixed mortar and coarse aggregate were supplied continuously with cut-gate method. The data available from the conventional mixing method in forced action mixer are also shown for the comparison. When using supplying method of cut-gate method, the elapsed time was noted less than 30 minutes. In this condition, the slump of concrete mixed in ESG mixer (13.5) was obtained within the limit range of designed value (15±2.5cm) and quite similar to that from the conventional mixer (15.5cm). The air content values of concrete mixed in the ESG mixer was 3.6% in comparison of 5.5% from the conventional mixer. 7 days and 28 days compressive strengths obtained from the concrete mixed in the ESG mixer were 30.9 MPa and 39.5 MPa respectively; whereas 30.5 MPa and 37.3 MPa were obtained from that of the conventional mixer. The slight increase of values in ESG mixer should be with the reason, as in earlier case, of the elapsed time of only 30 minutes in this case.

Average values and variation coefficients of compressive strengths shown in both table are of three specimens tested for each data. The variation coefficients in case of the ESG mixer were slightly larger than that of the conventional method, but all within the permissible range. It is expected that the variation coefficients may be minimized with automatic supplying system while mixing in ESG mixer.

It was confirmed that the ESG mixer is a very relevant mixer for mixing concrete with pre-mixed mortar and coarse aggregates resulting in similar quality to that of the conventional mixer. It reveals that the high productivity continuous mixing system is also possible to be developed for the high slump concrete. It is also expected that it may overcome the existing problems in screw type continuous mixer.

Conclusion

The following points are drawn as conclusions from this research work.

1. The modified mixing mechanism was possible to mix high slump concrete in 6 units of ESG mixer.

2. The slump value of 8cm slump concrete mixed in ESG mixer (5.6cm) was less than that mixed in the conventional mixer (9.5cm). It was due to the slump loss because of long elapsed time after the mixing of mortar (about 1.5 hour). It was verified by the further experiment.

3. Less air content in ESG mixer (3.6% in both both mix) than in conventional mixer (5.8% in AE 8 concrete and 5.5% in AE 15 concrete) should be due to the elapsed time and transportation of mortar.

4. The slump value of AE 15 concrete mixed in ESG mixer (13.5cm) was quite similar to that from conventional mixer (15.5cm) due to short elapsed time after the mixing of mortar (only 30 minutes).

5. For AE 8 concrete, the both 7 days and 28 days compressive strengths obtained from the concrete mixed in ESG mixer (22.5 MPa and 29.1 MPa) were higher than those from the conventional mixer (20.5 MPa and 24.9) MPa. It should be due to the long-elapsed time of mortar mixing (about 1.5 hour).

6. For AE 15 concrete, the both 7 days and 28 days compressive strengths obtained from the concrete mixed in ESG mixer (30.9 MPa and 39.5 MPa) were slightly higher than those from the conventional mixer (30.5 MPa and 37.3) MPa. It was due to less (30 minutes) elapsed time after the mixing of mortar.

7. Variation coefficients of compressive strengths in all cases were within the permissible range.

8. The above listed concluding points clearly showed the path to develop the high productive continuous high slump concrete production system using ESG mixer. With the achievement of this result, the high efficiency concrete mixing system was possible to develop in two real dam

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construction sites. The system was successful to produce whole types of concretes, namely high slump concrete, Dam and RCD concrete, in the continuous way, which ultimately reduced the whole construction period with maintaining all required properties of concrete in fresh as well as in the hardened state.

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