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Effect of re-vibration on the compressive strength and surface hardness of concrete

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Abstract. This paper reports the results of experimental investigations carried out on the effect of re-vibration on the compressive strength and surface hardness of normal weight concrete. Five different concrete mixes with varying water cement ratio ranging from 0.35 to 0.7 were prepared. The compacted concrete was subjected to re-vibration during the initial setting time period. During the initial setting time, the compacted concrete was re-vibrated at the time of 30 minutes up to 150 minutes of an interval of 30 minutes. The compressive strength and surface hardness of re-vibrated concrete were tested at the age of 35 days. The experimental results showed a significant increment of compressive strength and surface hardness in all re-vibrated concrete. In general, the maximum gain in compressive strength and surface hardness was when the re-vibration occurred at the initial setting time of 2 hours. The average increasing of the compressive strength of concrete by re-vibration is ranging from 3.5% to 21.8%.

1. Introduction

Entrapped air bubbles in the fresh concrete are needed to expel out. Blowholes or honeycomb will weaken the concrete strength and increase the porosity. Honeycombing will also reduce the bond between the concrete and reinforcement. Generally, every 1% of trapped air reduces the concrete strength by about 6%, therefore proper compaction is required in concrete construction [1].

Compaction is the process which expels entrapped air from freshly placed concrete and packs the aggregate particles together so as to increase the density of concrete. Compaction of concrete is a two-stage process as shown in figure 1. At the beginning stage concrete will liquefy and giving a level of top surface. In the second stage, entrapped air is expelled. The total time for both stages is around 10 to 20 seconds [2].

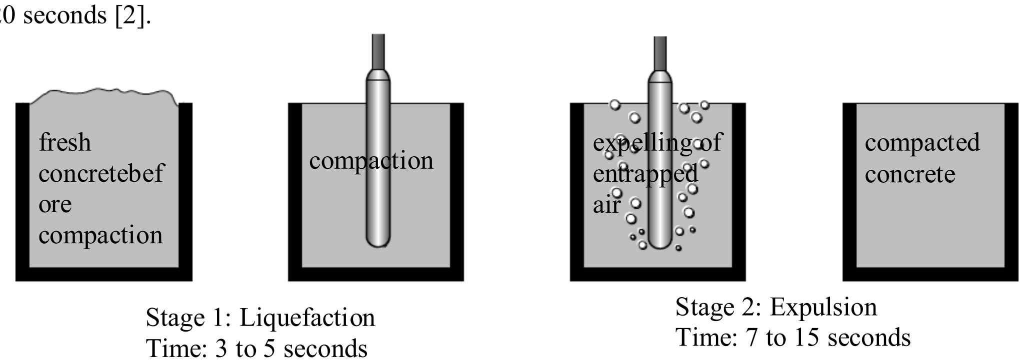

Figure 1. The process of compaction [2]

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Re-vibration of concrete can be defined as the application or process of vibration to concrete after completion of placing and initial compaction, but preceding initial setting of the concrete. Many of people believe that partially set concrete should not be disturbed and re-vibration may cause a loss of bond between steel and concrete [3]. However, re-vibration at 1 to 2 hours after placing showed an increment of the compressive strength of concrete by up to 15%, but the actual values depend on the workability of the mix. The improvement in strength is more pronounced at earlier ages, and is greatest in concretes liable to high bleeding since the trapped water is expelled by re-vibration [4]. Concrete which subjected to re-vibration is gained higher strengths and bond, better impermeability, reduction in shrinkage and creep, reduction in surface and other voids as well as cracks [5]. Re-vibration can be done usually at any time as long as the running internal vibrator can sink by its weight in to the concrete or when the external vibrator or vibrating table can liquefy the concrete momentarily. The accepted stiffness limit for re-vibration is then the penetration resistance of the standard steel needle specified in ASTM C 403 [6] reaches the value of 3.5 N/mm^2.

An experimental work has been carried out to study the effect of re-vibration on the compressive strength, and also on the surface hardness of concrete which has been not studied in the previous concerning researches.

2. Experimental Program

2.1 Materials and Concrete Mix

The materials for concrete mixes included Portland composite cement meeting MS EN 197-1:2007 [7] requirements, crushed granite aggregate with a nominal maximum size of 20 mm and fine aggregate was from river sand passing the 4.75-mm sieve and predominantly retained on the 75 μm sieve.

Five concrete mixes, based on the mix proportion used in previous study [5] are shown in table 1 were used in the study. The difference between the mixes was in the water cement ratio (w/c) and mix proportion between cement and total aggregate. M1 has the highest cement content with the lowest w/c. Meanwhile, M5 has the lowest cement content with the highest w/c. The Total aggregate is consists of fine aggregate and coarse aggregate. The w/c was 0.35, 0.5, 0.55, 0.6 and 0.7 for the five mixes. The cement to total aggregate ratio was 1:2.53, 1:4.3, 1:4.91, 1:5.51 and 1:7.01 for the five mixes. Meanwhile, the percentage of the fine aggregate over the total aggregate was fixed with 34.8%.

Table 1. Mix proportion

Mix	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water / Cement Ratio
M1	1	0.88	1.65	0.35
M2	1	1.50	2.80	0.5
M3	1	1.71	3.20	0.55
M4	1	1.92	3.59	0.6
M5	1	2.44	4.57	0.70

2.2 Specimens and Re-vibration Procedure

The concrete was mixed using portable electric concrete drum mixer. The fresh concrete was fully poured inside the 150 mm steel moulds and immediately initial vibration was applied using poker vibrator for about 10 seconds.To prevent the forming of honeycomb on the hardened cubes, observation during re-vibration is important by ensuring entrapped air is expelled out to the top surface. A total of 90 cubes were prepared,18 cubes for each concrete mix. Three compacted concrete cubes were vibrated again at 30, 60, 90, 120 and 150 minutes. Previous study had shown that re-vibration before the final setting time at 1 to 2 hours will benefit compressive strength of concrete [4]. Therefore, re-vibration was done before the final setting time of concrete. All cubes were de-mould after 24 hours and subjected to water curing. Figure 2 and figure 3 shows the vibration process and curing of specimens, respectively. The cubes were cured until the age of testing.

Figure 2. Vibration using poker vibrator

Figure 3. Concrete cubes subjected to water curing

2.3 Compressive Strength and Surface Hardness Tests

Three concrete cubes from each group were used to conduct the surface hardness and compressive strength tests at 35 days. The concrete cubes were have been scheduled for testing on day 28 but due to the availability of the rebound hammer then all cubes were tested at 35 days. Compressive strength test was conducted using concrete compressive machine of the loading rate of 0.6 MPa/s. Concrete cubes used for surface hardness are the cubes used for the compressive strength test. Rebound hammer 'DIGI-SCHMIDT 2000' (figure 4) was used for the surface hardness test. Rebound hammer test was conducted on 3 surfaces of each cube. 9 rebound readings were recorded for each surface.

Figure 4. Rebound hammer 'DIGI-SCHMIDT 2000'

3. Results and Discussions

3.1 Density of Hardened Concrete

Table 2 and figure 5 show the density of hardened concrete before and after re-vibration. It was found that concrete which has been vibrated again achieved higher density. The density of concrete was increased gradually after re-vibrated. All concrete achieved the highest density after re-vibrated at 120 minutes except M4 which achieved the highest density at 150 minutes. The highest density of concrete after re-vibrated was increased ranging from 0.3% to 3.0%.

Table 2. Average hardened density of concrete

Mix	Density (kg/m³)					
	Re-vibration Time (minutes)					
	0	30	60	90	120	150
M1	2326	2351	2354	2367	2381	2364
M2	2350	2351	2353	2356	2356	2355
M3	2282	2304	2319	2341	2350	2329
M4	2329	2362	2346	2348	2365	2391
M5	2334	2353	2363	2365	2378	2372

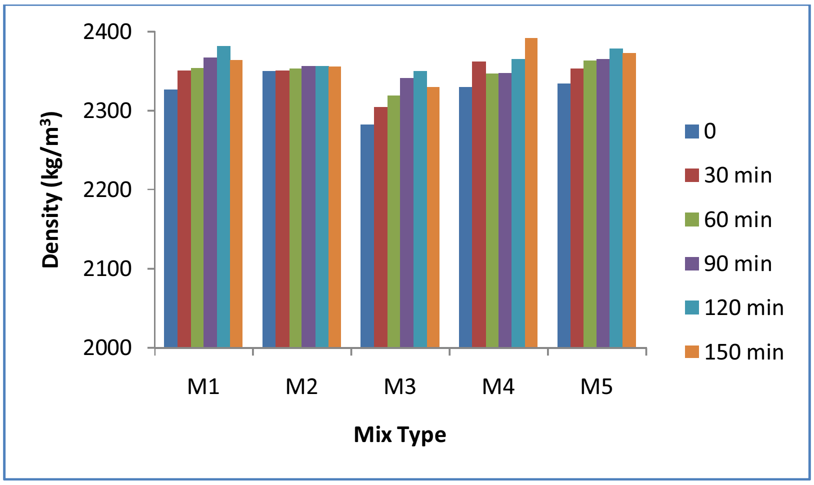

Figure 5. Hardened density of concrete

3.2 Compressive Strength

The 35-day compressive strength of 150 mm cubes of M1-M5 mixes are tabulated in table 3. In order to compare the relative gain of strength at different re-vibration time, the compressive strength of the mixes is also presented in figure. 6. As expected, M1 cubes with the lowest water/cement ratio and highest cement content has achieved the highest compressive strength. Compressive strength of M1 is approximately double of other mixes. All concrete have gained higher compressive strength after subjected to re-vibration. All concrete gained the maximum compressive strength resulting from the re-vibration applied at 2 hours after placing. An increment of compressive strength ranging from 3.5% to 21.9% was recorded for concrete subjected to re-vibration at 2 hours.

Table 3. Compressive Strength of Concrete

Mix	Average 35-day Compressive Strength (MPa)					
	Re-Vibration Time (minutes)					
	0	30	60	90	120	150
M1	62.8	63.6	67.3	68.9	70.8	68.4
M2	37.1	37.8	38	38.3	38.4	37.8
M3	33.7	33.1	34.8	37.5	38.9	33.9
M4	30.1	34.1	34.3	35.9	36.7	36.6
M5	26.2	29	29.1	30	29.3	29.3

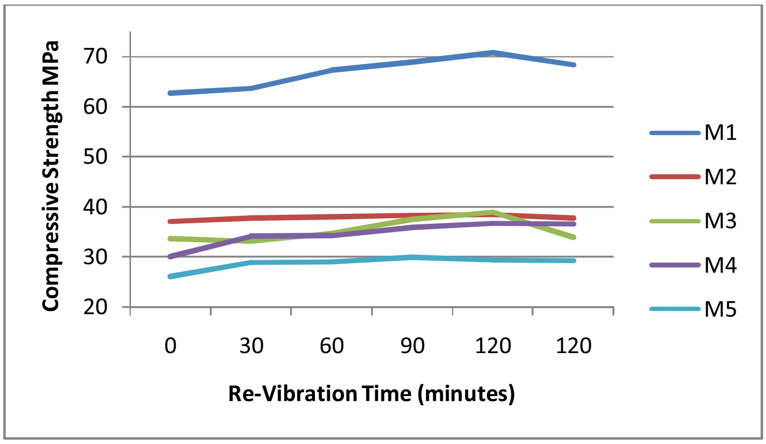

Figure 6. Compressive strength development of concrete subjected to re-vibration

3.3 Surface Hardness

Results of the average rebound hammer readings (27 rebound readings for each cube) are given in table 4. It can be noticed that re-vibration generally increases the surface hardness. All concretes except M4 gained the highest surface hardness resulting from the re-vibration applied at 2 hours.

Table 4. Average rebound hammer readings

Mix	Average Rebound Reading					
	Re-Vibration Time (minutes)					
	0	30	60	90	120	150
M1	34.7	36.7	37.3	38.3	38.5	38
M2	26.7	27.2	28.2	28.3	28.2	27.2
M3	26.2	27.5	27.3	28.7	29.3	27.3
M4	25.5	26.1	26.8	26.7	26.5	27.2
M5	22.7	23.0	23.1	23.2	23.2	23.0

4. Conclusions

Based on the results of the experimental work carried out in the present work, the following conclusions could be made:

1. Re-vibration applied on the concrete within the initial setting time has caused an increment of hardened density.
2. Re-vibration improves the compressive strength and surface hardness of hardened concrete.
3. Re-vibration at 2 hours after placing gained the maximum compressive strength.
4. Generally, maximum compressive strength is gained at which the concrete has maximum density and surface hardness.

5. References

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