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A Consistency Check of Concrete Compressive Strength using Pearson's Correlation Coefficient

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Abstract

The efficiency of the concrete ready mix service provider is undoubtedly and has become a widespread trend among contractors in which facilitates and eliminated a large budget surplus in maintenance, operating costs and is preferred as it reflects more efficient asset utilization. However, the quality assurance of concrete supplied is always raised associated with the inconsistencies of concrete compressive strength at the age of 28 days. The objective(s) of this study are to determine the correlations between the compressive strength of ready mix concrete, to evaluate the consistencies of the results and to identify the irregular sources that lead to the inconsistencies. Based on the compressive strength values obtained from the existing experimental data using different concrete mixes from the batching plant, a statistical analysis was conducted. A total of 90 concrete cubes specimens were attained from 15 concrete batches. A correlation analysis was conducted using the Pearson Correlation calculation to check the consistency of concrete compressive strength. The calculation showed the Pearson correlation coefficient of this study is +0.990. This indicated that there are significant linear relationship exists between the concrete compressive strength and the density of concrete batches which is positively high. In conclusion, the analysis reveals that the design of ready mix concrete compressive strength is in high consistencies and acceptable in practices for the proposed mix design to the contractor.

Keywords: Concrete; Compressive Strength; Coefficient; Pearson Correlation; Consistency.

1. Introduction

The concrete maturity indicated there are relationship between concrete compressive strength, density, and age of strength. As recommended for the construction of reinforced load bearing building structural members (columns, beams, and slabs) in mild exposure condition, the minimum cube strength for concrete mix design grade 25 is 25 MPa Kazeem et al. (2015) [1]. Vahid and Teshnehlab (2010) [2] stated that, the concrete sample is tested after 28 days and the result is considered as a criterion for quality and rigidity of that concrete. While, Metwally (2014) [3] has explained that hydration process takes place immediately after mixing cement-based materials and concrete starts to gain its strength. All concrete requires curing so that the cement hydration can take place to develop the strength, durability and other mechanical properties. This is supported by Price (1951) [4] that refers curing as the process of protecting

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concrete for a specified period of time after placement, provide moisture for hydration of the cement, provide proper temperature and to protect the concrete from damage by loading or mechanical disturbance. Raheem et al. (2013) [5] recommended six different method for curing were used until the testing ages of 3, 7, 14, 21 and 28 days. This claims also can be supported by Mamlouk and Zaniewski (2006) and Nassif and Suksawang (2002) [6, 7] that stated that if the concrete is allowed to dry in air and not cured properly, it were unable to gain the required properties at the anticipated level.

Demands for concrete ready-mixed made tremendous significant to the construction industries. However, the quality of ready-mixed concrete must be controlled to avoid deleterious reactions in terms of construction quality. Laboratory systems that were developed to control the quality of concrete without measurements to check the intensity of the reactions in the actual concrete by using analytical formula. Thus, this study initiated to enhance the existing method by employing analytical formula which is viewed as innovation in concrete quality control as whole.

Ashish and Jayeshkumar [8] stated that, the definition where, ready mixed concrete (RMC) as concrete mixed in a stationery mixer in a central batching and mixing plant or in a truck mixer and supplied in the fresh condition to the purchaser either at the site or into the purchaser's vehicles. Thus, in concrete mix design, it often to practice where contractor on demand required to prepare the ready mix concrete design and normally it would be provided by the concrete ready mix supplier to control the concrete quality assurance and to obtain the appropriate mix ratios to achieve the required concrete grade or strength class. In spite of considering the 28 days compressive strength for design purposes, the inconsistencies of compressive strength ready mix concrete occasionally be questioned. There are many factors in influencing the consistency of strength gained. Vipin et al. (2014) [9] in their study has explains that, compressive strength of concrete is a major and perhaps the most important mechanical property, which is usually measured after a standard curing of 28 days. Concrete strength is influenced by lot of factors such as concrete ingredients, age and ratio of water to cementious materials. Despite of that, the objective of this study is to identify whether the initial design of ready mixed concrete with the highest potential meets customer's needs consistently.

Existing methods of mix proportioning require large number of trial mixes to select the desired combination of materials and has to minimize the number of trial mixes to achieve an economical and satisfactory mixture to meet the desired properties Kale and Kute (2014) [10]. In present paper an attempt has been made to design a proportion of ready-mix concrete design based on British Standard method. For the construction projects, cost, quality, and time are parameters that need to be optimized [11].

This research aim at defining the influence of the initial ready-mix concrete design to the various compressive strength of high-performance concrete depending Pearson's correlation as shown in Equation 1. It can take a range of values from +1 to -1 from low, moderate, and high of association class.

$$r = \frac{n(\sum x_i y_i) - (\sum x_i)(\sum y_i)}{\sqrt{n(\sum x_i^2) - (\sum x_i)}\sqrt{n(\sum y_i^2) - (\sum y_i)^2}} \quad (1)$$

Where, r = Pearson correlation coefficient; n = Number of samples; x_i = x variable; x_i = y variable.

The specimens are tested by compression testing machine after 7 days and 28 days of curing. The aims of this study are:

- To determine the correlations between the compressive strength of ready mix concrete;
- To evaluate the consistencies of the results;
- To identify the irregular sources that leads to the inconsistencies.

2. Materials and Methods

The preparation of Ready Mixed Concrete (RMC) are mixed in batching plant and the materials used for the production of concrete test specimens grade 25 are ordinary Portland cement, fine sand, granite as aggregate and tap water. The proportion and design controlled as shown in Table 1. Fine aggregate type used from washed river sand. Cleaned from debris through desilting process at zone IV. In Sabah, Malaysia the fine aggregate or river sand are classified to four classes or grades. The best grades at zone IV in which raw material is very fine. Coarse aggregate from crushed granite size ranges from 10 to 20 mm. All aggregates were ensured to be free from deleterious substances such as organic impurities, clay and other unsound particles. Ordinary Portland cement was used as binder in this study. The grading of fine and coarse aggregates was determined in accordance with procedure in BS 1377 (1990), Part 2:92 [12], Methods of Test for Soils for Civil Engineering Purposes Classification Tests. Figure 1 summarized the research methodology of this study.

2.1. Preparation of Concrete and Test Specimens

Ready mix concrete mixing has been batched for 15 batches in one mix design as stated in Table 3 with 102 concrete cubes prepared with size 150×150×150 mm. This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in the water for curing.

These specimens are tested by compression testing machine after 7 days curing and 28 days curing in normal tap water. Compressive strength test of concrete has been conducted according to BS 1881-116:1983 [13]. Minimum three specimens were tested at each selected age for each group. A sample controlled with same design has been prepared separately and the strength recorded as main indicator testing to ensure that it complies with the requirements of the project specification. The acceptance of concrete compressive strength for grade 25, the minimum compressive strength at 7 days in 17 N/mm^2 and specified characteristic compressive strength at 28 days is 25 N/mm^2 as per guided in BS 1881:116 (1983) [13].

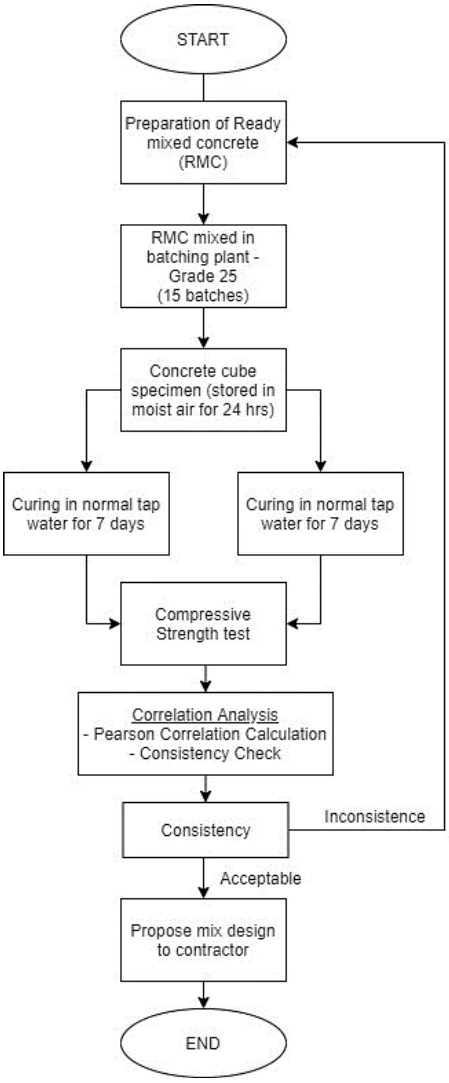


Figure 1. Research Methodology

A standard mix ratio of 1:2:4 was used in this study and widely used in batching plant service provider. Batching by weight was adopted and casting of all specimens was carried out under same ambient conditions of average temperature 27 °C and 75% relative humidity as per conducted by Raheem et al. (2013) [5]. The water cement ratio used for the mix was 0.49 and maintained for all subsequent mixes or 170 kg/m^3 for every 350 kg/m^3 ordinary Portland cement. The concrete was prepared by using mixer truck. The steel cube mounds cleaned and oil applied. The mixed concrete was placed into the mould in three layers. Each layer of concrete was compacted by not lesser than 35 strokes of a 25 mm diameter tamping steel rod with free dropped. Concrete filled in the moulds in layers approximately 50 mm thick. After final layer compacted accordingly, the top surface levelled and smoothen with a hand trowel. The test cube specimens are stored in moist air for 24 hours and after this period the specimens are marked and removed from the moulds and kept submerged in tap water until taken out prior to test. The water for curing were tested in every 7 days and temperature of water are set to be at 27 ± 2 0C. The curing method was applied is Water Submerged Curing (WSC), the submersion of the concrete cube specimens in water Raheem et al. (2013) [5].

Table 1. Concrete mix design description

Characteristic	Design controlled
Specified Slump Test	100 ± 25 mm
Cement Type	Ordinary Portland Cement
Fine Aggregate Type	Washed river sand
Coarse Aggregate Type	Crusher granite 20 and 10 mm
Concrete Grade	25
Size of cube	150×150×150 mm
Density of fine aggregate	2600 kg/m^3
Density of coarse aggregate	2630 kg/m^3
Cement O.P.C	350 kg/m^3
Water ratio	0.49
Water	170 kg/m^3

2.2. Correlation Analysis

A correlation analysis was conducted, and the Pearson correlation coefficient was calculated. Table 2 shows the classification of Pearson's Correlation and absolute ranges of values. It can be clearly determined that, in the range of less than 0.5, the value indicated as moderate to very weak or not correlated. In this study, the correlation was determined more than 0.5 which is +0.990, the correlation of ready-mixed concrete design is classified as very strong.

Table 2. Class of Pearson Correlation and absolute ranges of values [14, 15]

Class	Range – absolute value
Not correlated/Very weak	< 0.1
Weak	0.1 to 0.2
Moderate	0.2 to 0.5
Strong	> 0.5
Very strong	> 0.5

3. Results and Discussions

The results for 7 days and 28 days compressive strength have been summarized in Table 3, where the relationship between density and compressive strength inseparableness. The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates and water. The scale of mixtures consistently used. Therefore, the results are compared to study the acceptance interpretation using Pearson's correlation.

3.1. Density and Compressive Strength of Concrete Ready Mix

Figure 1 shows the density of various concrete ready-mix batch relationship with compressive strength. The established relationship between compressive strength and density was done through the determination of Pearson's correlation coefficient. Compressive test has been conducted for concrete at an age 7 days where controlled specimens was recorded 21.92 and 29.03 N/mm^2 at an age 28 days. After 28 days of curing, specimens recorded increment 7.11 N/mm^2 initial strength at 7 days or 24.5% increment. However, the concrete cube specimens for the rest 34 batches concrete mixes has recorded relatively scattered and inconsistence. At an age 7 days, variously demonstrates concrete strength, 5 mixes batches surpassed the minimum specified characteristic compressive strength at 28 days achieves 25 N/mm^2 earlier than required days. For instant, all specimens are defined passes the required minimum compressive strength for 7 days at 17 N/mm^2. At the age of 28 days compressive strength, the strength cumulated approaching the controlled of concrete are varies and often ununiformed, slightly passes the specified characteristic compressive strength at 28 days for grade 25 at 25 N/mm^2. There are linear increments recorded and mostly 20 to 33% increased from 7 days aged.

From the computation, it indicates that, there is a significant linear relationship exists between density and compressive strength. The result has shown positive variance with ρ = +0.990 and classified as high association proved by Pearson's correlation. On the other hand, Raheem et al. (2013) [5] computed, +0.278 for compressive strength with density correlation and classified as weak positive correlation. Thus, the concrete design for ready mix concrete in this study corresponds to the exact requirements of customer and as stated in standard followed. In summary, the density of concrete increased accordingly with compressive strength as found in Figure 1.

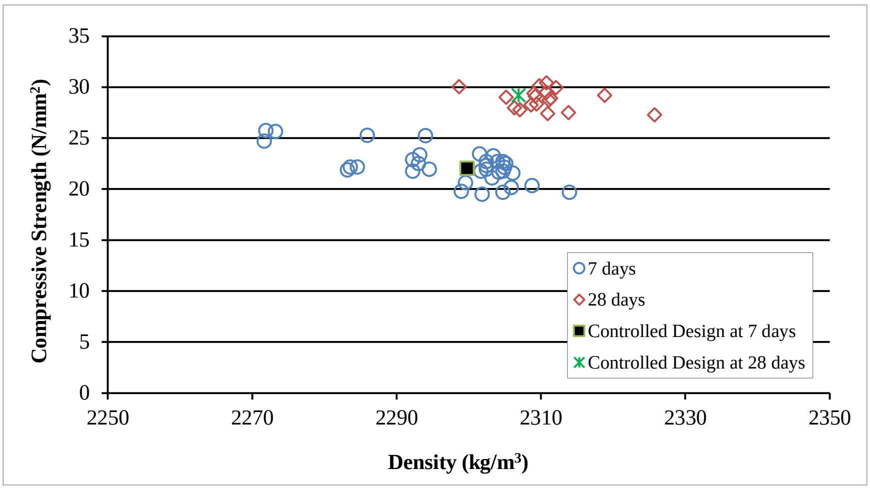


Figure 1. Density of various concrete ready-mix batch

Table 3. Relationship between Density and Compressive Strength

Concrete Batch Group	Curing Period (Days)	Density (kg/M^3)	Strength (N/mm^2)	Rank A = X_i	Rank B = Y_i	X_iY_i	X_i^2	Y_i^2
1	7	2299	20.00	19.11	20.00	382.2	365.2	400.0
	28	2310	27.33	27.77	27.77	771.2	771.2	771.2
2	7	2300	20.88	20.44	21.11	431.5	417.8	445.6
	28	2310	28.00	27.77	28.00	777.6	771.2	784.0
3	7	2299	22.22	22.00	22.66	498.5	484.0	513.5
	28	2307	28.88	28.88	29.11	840.7	834.1	847.4
4	7	2299	21.77	21.77	22.22	483.7	473.9	493.7
	28	2311	27.77	27.77	28.22	783.7	771.2	796.4
5	7	2305	20.22	20.00	20.22	404.4	455.0	408.8
	28	2307	28.88	27.77	29.11	808.4	796.4	847.4
6	7	2300	21.55	21.33	21.55	459.7	382.2	464.4
	28	2310	28.22	28.22	28.44	802.6	735.0	808.8
7	7	2275	19.77	19.55	20.00	391.0	382.2	400.0
	28	2334	27.55	27.11	27.55	746.9	735.0	759.0
8	7	2301	19.77	19.55	19.77	386.5	473.9	390.9
	28	2334	27.11	27.11	28.00	759.1	834.1	784.0
9	7	2300	22.00	21.77	22.22	483.7	356.5	493.7
	28	2311	29.11	28.88	29.33	847.1	821.4	860.2
10	7	2301	20.00	18.88	20.22	381.8	523.5	408.8
	28	2311	28.88	28.66	29.11	834.3	847.4	847.4
11	7	2300	23.33	22.88	23.33	533.8	493.7	544.3
	28	2311	29.33	29.11	29.58	861.1	821.4	875.0
12	7	2305	20.44	22.22	23.33	518.4	408.8	544.3
	28	2311	29.33	28.66	29.55	846.9	834.1	873.2
13	7	2307	20.44	20.22	20.66	417.7	493.7	426.8
	28	2308	29.11	28.88	29.11	840.7	834.1	847.4
14	7	2301	22.88	22.22	22.88	508.4	493.7	523.5
	28	2310	29.33	28.88	29.33	847.1	834.1	860.2
15	7	2299	22.00	21.33	22.22	474.0	455.0	493.7
	28	2311	28.88	28.82	29.11	839.0	830.6	847.4
			∑=	737.56	753.71	18961.3	18573.4	19361.2

Therefore, the calculation carried out as follows:

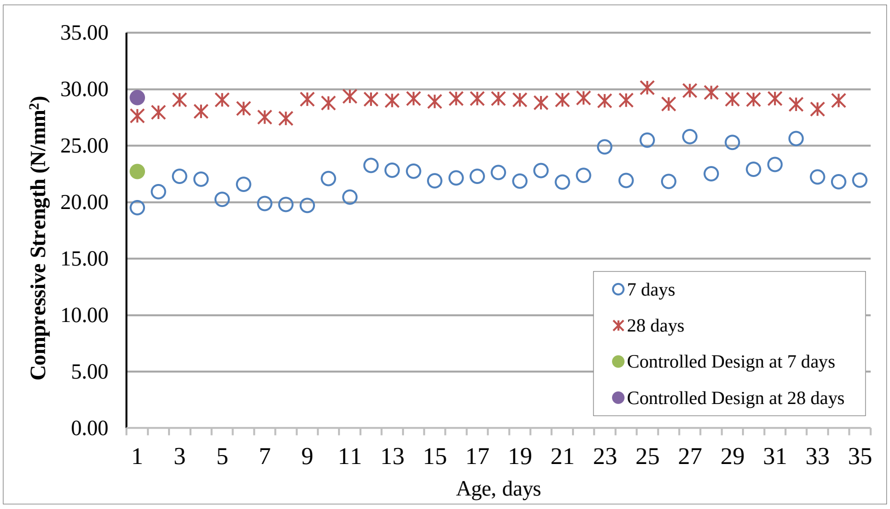
$$r = \frac{n(\sum x_i y_i) - (\sum x_i)(\sum y_i)}{\sqrt{n(\sum x_i^2) - (\sum x_i)}\ \sqrt{n(\sum y_i^2) - (\sum y_i)^2}} = +\,0.99$$

Addressing the inconsistencies skepticism on the compressive strength test results itself, the Pearson's correlation was used to determine the relationship between the density and compressive strength in the interpretation of strength association as described to ensure the result high efficiency and acceptable. Table 3 shows the relationship between density and compressive strength for 15 batches mixes which are considered surpassed the requirements.

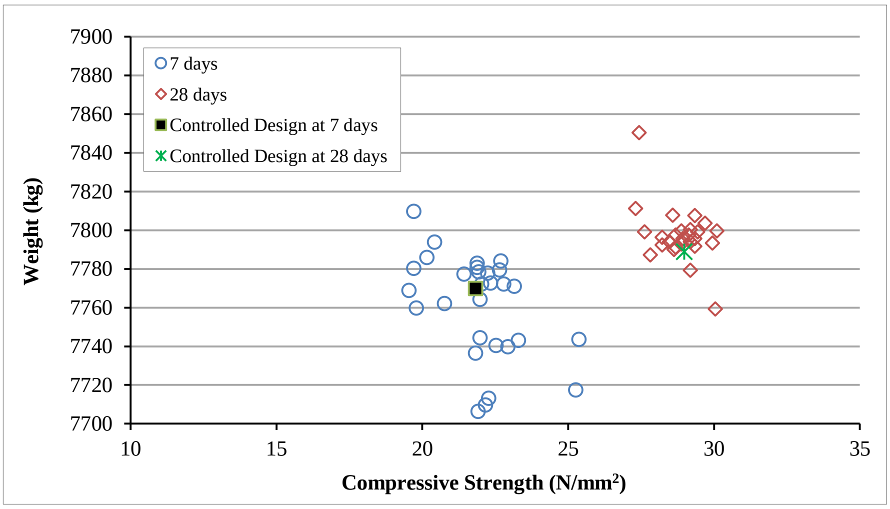
3.2. Weight of Concrete Ready Mix

The observed weight of concrete ready mixed interpreted by weight and compressive strength relationship. It has been witnessed that, the weight of concrete behavior scattered over the controlled specimens. The weight of each specimen slightly varied due to unknown criteria. Comparisons between 7 and 28 days patterns, there are no significant differences. As can be seen, the weight over compressive strength more converge than 7 days weight skeletons.

In summary, it has been observed that, the weight of concrete increased marginally with compressive strength. There has been recorded 17 to 24% increment in this relationship. As the weight increases, the compressive strength of the concrete will increase. The strength of concrete increases with age. It has been notched in Figure 2 (a). At the age of 7 days, compressive strength passed the 17 N/mm^2 and notched ranges from 20 to 26 N/mm^2 randomly. There are rapidly increase and surpasses the requirements at 28 days where, the compressive strength surpassed 25 N/mm^2 and some cubes reached strength to 30 N/mm^2.



(a) Compressive strength versus age



(b) Compressive strength versus weight

Figure 1. Relationship of Compressive Strength to Weight

Weight of concrete increased relatively to compressive strength the age of concrete itself as shown in Figure 2b and normally leads to the elasticity of concrete. The correlation of elasticity in concrete strength has been stated, where the modulus elasticity related to the compressive strength increases [16]. At the age of 28-day, the compressive strength gradually increased and pass through the requirement of engineering strength criteria. It is generally accepted that within the normal range of strengths in concrete construction, the compressive strength is inversely proportional and almost linearly related to water content or water-cementitious material ratio. Also, concrete strength decreases with increased air entrainment [17].

4. Conclusions

Based on the experimental investigations the following conclusions are drawn. The Factors that have been observed to rely on, and that have long been thought to be useful indicators, turned out to have consistence and uniformity to high association proved by Pearson's correlation.

The ready mix concrete is in high consistency and meets the engineering requirements. Although the 28-day strength generally increases as density increases. For the entire data uniformity set, there was a significant correlation between 7-day and 28-day strength and concrete density where the data was recorded differences in small range due to differences the existence aggregate moisture content and accompanied by irregular shape of course aggregate to produce a friction force. The proposed ready mix design that has been used can be adopted and accepted for the high consistency concrete quality.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available in article.

5.2. Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

5.3. Conflicts of Interest

The authors declare no conflict of interest.

6. References

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