Assessment factor

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Assessment Factor of Strength Development for Normal, High Strength, and Lightweight Concrete

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***Abstract*—Development in the construction sector continues to increase. The most common building material nowadays is concrete. Although normal concreteis often being used, at this time high strength concrete and lightweight concrete have also been widely used in construction. In the codes for concrete materials, either SNI 03-6805-2002 or PBI NI-2 1971, it is stated about the assessment factor of compressive strength development for normal concrete according to the age of the concrete. However, these codes have not accommodated the assessment factor for high-strength and lightweight concrete. An experimental approach was used to determine the assessment factor and is discussed in this paper. The specimens were cylinders of high strength concrete, normal concrete, and lightweight concrete and tested for compressive strength at the age of 3 days, 7 days, 14 days, 21 days, 28 days, 56 days, and 90 days. The results showed that the compressive strength of the concrete increased with increasing age of the concrete. The assessment factor for the development of compressive strength of high-strength concrete showed the highest value, while lightweight concrete showed the lowest factor. The assessment factor of compressive strength development for normal concrete lies between the value given in PBI NI-2 1971 and SNI 03-6805-2002, where the factor from SNI 03-6805-2002 has the highest value.**

Keywords—normal concrete, high strength concrete, lightweight concrete, assessment factor, compressive strength

I. INTRODUCTION (*HEADING 1*)

One of the most widely used for building materials is concrete due to its high compressive strength and other advantages. Normally, concrete is a mixture of a normal coarse and fine aggregate, cement, and water in a certain ratio to produce a normal or conventional concrete. Normal concrete has a weight of 2200-2500 kg/m^3[1]–[3].

Concrete technology has been developing forward and discovering concretes with various modifications, such as lightweight concrete and high-strength concrete [4]–[6]. Lightweight concrete is a concrete that has a specific gravity lighter than normal concrete in general. It offers a benefit mainly in reducing the seismic load sustained by the structure. According to ASTM C567 concerning of Standard Test Method for Determining Density of Structural Lightweight Concrete and SNI 2487-2019 concerning of Procedure for Calculation of Concrete Structures for Building and Non-Building, lightweight concrete is determined as a concrete with density between 1140 and 1840 kg/m^3.

Meanwhile high strength concrete has a higher compressive strength compared to normal concrete commonly; therefore the dimension of the structural element can be reduced. In addition, high strength concrete is a concrete that has a higher mechanical properties when compared to ordinary normal concrete. High-strength concrete is classified as concrete which has a compressive strength of between 40-80 MPa. According to the code of Procedure For Planning A Mixture Of High Strength Concrete With Portland Cement and Fly Ash [7], high-strength concrete is defined as concrete having a required compressive strength greater than 41,4 MPa. High strength concrete has a higher compressive strength because the mixture uses certain material admixtures.

The assessment factor is used to predict the compressive strength of concrete at a certain age. The age of 28 days is used as a standard in determining this factor assessment because concrete compressive strength is at 99% in 28 days, it is very close to its final strength. In terms of the development of compressive strength, based on the code: SNI 03-6805-2002 it is stated that the ratio of the age of concrete to the compressive strength of concrete is directly proportional [3], [8]–[10]. There has been an assessment factor for concrete compressive strength development either in the current code (SNI 03-6805-2002) [11] or the outdated concrete code (PBI NI-2 1971) [12], namely for 3 days, 7 days, 14 days, 21 days, 28 days, 90 days and 365 days. However the assessment factor for concrete compressive strength development stated in those codes is only for normal concrete, while for high-strength concrete and lightweight concrete does not yet exist.

Therefore, this paper provides a discussion of the assessment factor for concrete compressive strength development based on the results of the experimental approach in the laboratory.

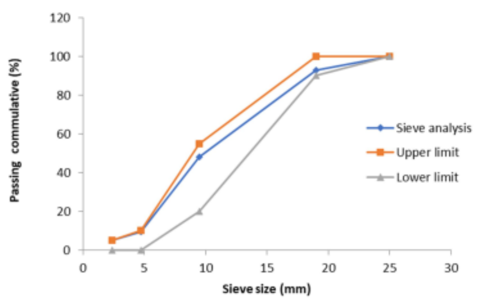
II. METHODOLOGY

A. Material

The main materials used in this research were cement, coarse aggregate, fine aggregate, and water. Pozzolan portland cement (PPC) type I manufactured by Tiga Roda was used as cement material. Coarse aggregate in the form of crushed stone with a maximum diameter of 20 mm was used in normal and high strength concrete, whereas pumice with a maximum diameter of 20 mm was used as coarse aggregate in lightweight concrete. All types of concrete used fine aggregate of river sand with a maximum diameter of 4,75 mm. The examination of the aggregate was according to the national standard [13]. The aggregate properties are shown in Table 1 and Figure 1.

Tabel 1. Properties of aggregates

Properties	Aggregate type		
	Fine aggregate	*Normal coarse aggregate*	*Lightweight coarse aggregate*
Saturated surface dry density (kg/cm^3)	2588	2660	1200
Finess modulus	3,4	6,33	6,34
Impurities content (%)	1,85	1,06	1,62
Los Angelos abrassion resistant (%)	-	26,24	26,98



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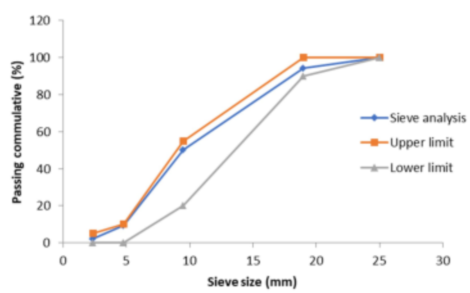

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Figure 1. Sieve analysis of (a) normal coarse aggregate and (b) lightweight coarse aggregate

B. Concrete Mixture Proportion

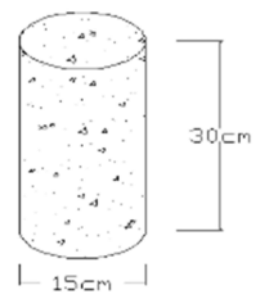
Three types of concrete were prepared in the experiment, namely normal concrete, high strength concrete, and lightweight concrete. Normal concrete was designed with a quality of 25 MPa at the age of 28 days and a water-cement ratio of 0,61. High-strength concrete was designed with a quality of 45 MPa and a water-cement ratio of 0,3. Both normal concrete and high strength concrete utilized coarse aggregate in the form of crushed stone. Due to the low water-cement ratio, the high-strength concrete required superplasticizer to increase its workability. Likewise, to achieve a high quality, the high-strength concrete mixture was added of silica fume as much as 10 percent of the cement weight. Furthermore, lightweight concrete was designed to achieve a quality of 17 MPa and a water-cement ratio of 0,58. Pumice was used as coarse aggregate in this lightweight concrete mix. The mixture proportion of each concrete type is explained in Table 2 [3].

Tabel 2. Concrete mixture proportion

Mixture Proportion (kg/m^3)	Concrete type		
	Lightweight concrete	*Normal concrete*	*High strength concrete*
Water	327,2	167,2	178,5
Cement	414,2	336,1	683,3
Sand	414,3	964,6	569,1
Crushed stone	-	923,4	923,4
Pumice	388,1	-	-
Silica fume	-	-	68,3
Superplastisizer	-	-	4,1

C. Specimens and Testing

The specimens were standard concrete cylinder with a diameter of 150 mm and a height of 300 mm. Testing was conducted by applying a compressive load to the test object until failure [14]. Tests were carried out at the specimens ages were 3, 7, 14, 21, 28, 56, and 90. The sketch of the specimen and the method of testing can be seen in Figure 2.



(a)

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(c)

Figure 2. The sketch of the specimen (a), the specimens (b), and the method of testing (c)

III. Result and Discussion

A. Fresh Concrete Properties

In general, the slump value is obtained between 7,5 cm - 12 cm for all types of concrete which means that a mixture of lightweight concrete, normal concrete, and high strength concrete are workable or being processed well. Lightweight and normal concrete reach the slump value of 7,5 cm and 8 cm respectively. Unlike high strength concrete, due to the lower water-cement ratio, a superplasticizer is required in the mixture so that the mixture reached a slump value of 12 cm. The superplasticizer used is Viscocrete 1003 with an amount of 0.6% by weight of cement. Table 3 shows the average of slump values of each concrete type.

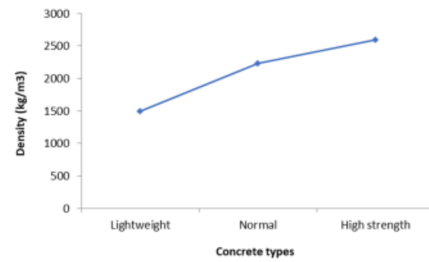
Tabel 3. Concrete slump value

Type	Average of slump (mm)
Lightweight concrete	7,5
Normal concrete	8
High strength concrete	12

B. Properties of the Concrete on 28 Days Curing time

Post curing time of 28 days, lightweight concrete reaches a density of 1500 kg/m^3. This value corresponds to those of structural lightweight concrete required by SNI 2847-2019, which is 1140-1840 kg/m^3. Similarly, the compressive strength of 28 days, which is 18 MPa, meets the requirements as lightweight concrete for structural applications.

Normal concrete has a volume weight of 2230 kg/m^3 and a compressive strength of 32,7 MPa at the age of 28 days. Both in terms of density and compressive strength, this concrete meets the requirements to be applied as a structural element. Likewise, high-strength concrete has a compressive strength of 62,3 MPa, which has exceeded the minimum compressive strength required for high-strength concrete, which is 41.4 MPa. The concrete density and compressive strength after curing time of 28 days are illustrated in Figure 3.



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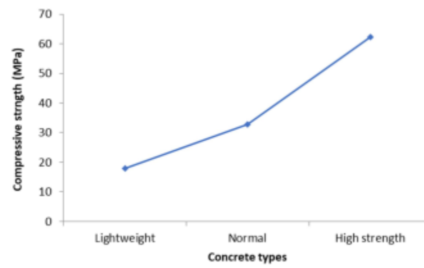

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Figure 3. Density (a) and compressive strength of each concrete type after 28 days curing time

C. Strength Development

The results of the compressive strength test show an increase in the compressive strength of the concrete along with the increase of the concrete ages even though the concrete has passed the age of 28 days. For normal concrete, the maximum compressive strength of concrete is obtained at the age of 90 days reaching 34,91 MPa. Meanwhile, for at the age of concrete 3 days, 7 days, 14 days, 21 days, 28 days and 56 days, the compressive strength are 19,72 MPa; 22,84 MPa; 26,80 MPa; 29,44 MPa; 32,65 MPa; and 33,88 MPa respectively.

The same trend is also found in lightweight concrete and high-strength concrete. In high-strength concrete, there is a strength development at concrete ages of 3 days, 7 days, 14 days, 21 days, 28 days, 56 days and 90 days at 45,20 MPa; 50,58 MPa; 54,54 MPa; 57,56 MPa; , 62,28 MPa; 65,30 MPa; and 69,45 MPa respectively. Furthermore, in lightweight concrete, the strength development occurred at variations in the age of concrete 3 days, 7 days, 14 days, 21 days, 28 days, 56 days and 90 days at 8.49 MPa, 10.29 MPa, 13,40 MPa; 15,85 MPa; 17,74 MPa; 18,59MPa; and 18,97 MPa respectively. In the case of lightweight concrete strength development after 28 days it does not show a significant increase, but in high-strength concrete there was still a significant increase in strength. Figure 4 shows strength development in each concrete type.

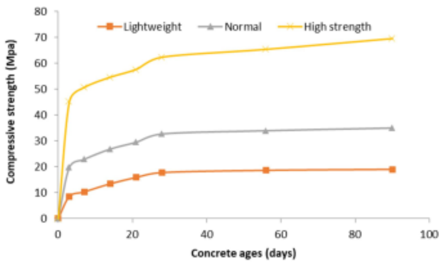

Figure 4. Strength development in each concrete type

D. Assessment Factor

When the compressive strength of concrete at the age of 28 days is normalized to a value of 1, a comparison of the compressive strength at a certain age is obtained which is called the assessment factor. The assessment factor on lightweight concrete for ages of 3, 7, 14, 21, 56, and 90 days, respectively, was 0,48; 0,58; 0,76; 0,89; 1,05; and 1,07. Meanwhile, for normal concrete, the assessment factors are 0,6; 0,70; 0,82; 0,90; 1,05; and 1,07 for concrete ages of 3, 7, 14, 21, 56, and 90 days respectively. Furthermore, the assessment factor for high-strength concrete showed values of 0,73; 0,81; 0,88; 0,92; 1,06; and 1,12 respectively for concrete ages of 3, 7, 14, 21, 56, and 90 days.

Figure 4 shows the comparison of assessment factors among the concrete types. It can be seen that before the age of 28 days, lightweight concrete has the lowest assessment factor but after 28 days of age, the assessment factor of lightweight concrete equals the assessment factor value of normal concrete. Among the three types of concrete, high-strength concrete has the highest assessment factor, where the assessment factor continues to increase sharply even though the concrete reaches 90 days old. The role of silica fume which is able to bind calcium hydroxide so as to provide a continuous pozzolanic reaction which causes the strength of the concrete to continue to increase significantly after the concrete is 28 days old [8], [9], [15]–[17].

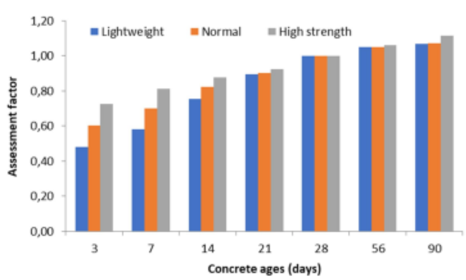

Figure 4. Concrete assessment factor

E. Assessment Factor Comparison to the Codes

Figure 5 shows the comparison of the assessment factor between the concrete codes: PBI NI-2 1971 , SNI 03-6805-2002, and the experimental results for normal concrete because the codes do not accommodate other types of concrete. In general, it appears that the assessment factors from the three sources are not much different. The biggest difference is in the early age especially at 3 days where the difference is around 30% in the assessment factor between PBI NI-2 1971 and the experimental results. This is assumed to be due to the use of different types of cement. The experiment used pozzolan portland cement or PPC because currently, this type of cement is commercialized in the market. This PPC contains higher calcium tri silicate hydrate or C_3S element so that it produces higher heat of hydration in the early age; as a result high compressive strength is achieved at the beginning [18]. As for PBI NI-2 1971, it is assumed to use ordinary portland cement because this code is oudated and at that time the cement available in the market was still ordinary portland cement or OPC.

For compressive strength above 28 days, which is 90 days, the experimental results show a lower assessment factor because the C_3S component does not provide a high final strength. Furthermore, SNI 03-6805-2002 does not provide an assessment factor for the concrete age of 14 and 21 days; therefore in Figure 5 only shows the assessment factor from PBI NI-2 1971 and the experimental result for those concrete ages. The assessment factor of the two is found not much different.

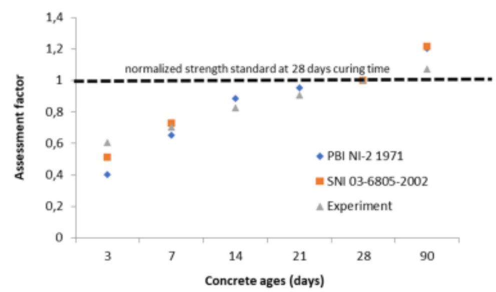

Figure 5. Assessment factor comparison

IV. Conclusion

This paper discusses the assessment factor of strength development for high strength, normal, and lightweight concrete. The assessment factor on lightweight concrete for ages of 3, 7, 14, 21, 56, and 90 days, respectively, was 0,48; 0,58; 0,76; 0,89; 1,05; and 1,07. Meanwhile, for normal concrete, the assessment factors are 0,6; 0,70; 0,82; 0,90; 1,05; and 1,07 for concrete ages of 3, 7, 14, 21, 56, and 90 days respectively. Furthermore, the assessment factor for high-strength concrete showed values of 0,73; 0,81; 0,88; 0,92; 1,06; and 1,12 respectively for concrete ages of 3, 7, 14, 21, 56, and 90 days.

Among the three types of concrete, high-strength concrete has the highest assessment factor, where the assessment factor continues to increase sharply even though the concrete reaches 90 days old.

The assessment factor between the concrete codes: PBI NI-2 1971, SNI guideline 03-6805-2002, and the experimental results for normal concrete shows that in general, it appears that the assessment factors from the three sources are not much different.

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