Relationship Between Core Compressive Strength and UPV Values for Different Core Slenderness of High Strength Concrete Beam

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ABSTRACT

The compressive strength of core concrete is affected by many parameters and one of them is the strength of the concrete, which affects the strength of the core compressive strength. This is achieved by using correction factors present in several standards such as ASTM C 42/C 42M-04, but this standard was not considered for high and very high strength concrete (HSC). In this study, a beam of (1x 4x 0.2) m constructed with 100 MPa target strength for core samples. Four different core diameters (25-50-75-100) mm and for each diameter different core length-diameter ratios(λ=l/d) (2-1.75-1.5-1.0) were extracted from the beam for assessing the strength in both casting directions. The relationship between the strength of concrete with respect to reference samples and different cores size with different slenderness ratio, length to diameter (λ) were investigated. The Ultrasonic Pulse Velocity (UPV) was conducted for all samples and the relationship between UPV and strength of cores were determined. The results showed that the core strength was increased with the decrease of slenderness ratio. Core samples correction factors to predict the strength of standard cylinder for HSC beam are different from normal strength concrete (NSC) and they have ranged between 1.0 and 1.12 for beam. Relationship between core compressive strength and UPV values are established.

KEYWORDS: *Core slenderness; high strength concrete; UPV; core compressive strength; core correction factor**s.***

INTRODUCTION

A simple method is presented for the determination of an equivalent specified strength of concrete, using a number of core tests, which can be substituted directly for the specified strength in conventional design equations to assess the safety of an existing structure. The HSC ranges from 50 MPa to 125 MPa developed and used in the construction of high-rise buildings and long span bridges in many parts of the world. There are a lot differences in behavior of the NSC& HSC, such as stress strain relationships, modulus of elasticity and fracture, for this reason we cannot use the same correction factors that are mentioned in ASTM-C42/C42M for HSC .The results of compressive strength of cores concrete are affected by the sensitivity of measured strength to the l/d ratio, the core moisture condition,

The core diameter and the orientation of core axis with respect to direction of casting. It was concluded that concrete cores with smaller diameters have smaller compressive strength [6].

Tuncan [24] has reported that compressive strength of concrete decreases as the maximum aggregate size increases. For instance, it was observed that the relative strengths of (small) diameter cores with respect to standard cylinder specimen were 72 % and 85 % for cores extracted from concretes

Ali Ergun and Gokhan Kurklu [13] studied the relation between the compressive strength of cores drilled from NSC elements and molded cylinder and cube specimens.

They found that the coefficient of correction factor values increased with the decrease in core diameters, changes in the compressive strength for 100 and 75 mm diameter cores were found to be more significant and reliable when compared to those of 50 mm diameter cores.

Indelicato [16] estimated concrete cube strength by means of different diameter cores by a statistical approach. There were very strong linear correlations between mean cube strength values and the mean strength values determined on cores of the three diameters studied (28, 45 and 70 mm). He found that the correlation laws were very close, with straight lines displaying angular coefficients very close to 1, but with increasing specimen diameter, the identity between cube and core mean strength improves, albeit slightly.

Bartlett and MacGregor [15]conducted a study to investigate the effect of moisture condition on the strength of mature cores extracted from concrete blocks.. The strengths of samples concrete were ranging from (15 to 92) MPa. They reported that the strength of cores is affected by change in moisture content between drilling and testing instead of total moisture content at the time of testing. Cores that left to dry was 14 percent larger than that of soaked strength cores. They concluded that correction factors for moisture curing condition were 1.09 and for immersed and air-dried cores were 0.96. In another study,

Bartlett and MacGregor.[4] in another research were conducted of cores of high performance concrete in beams. They concluded that core contain flay ash with axes parallel to the casting direction is 14 percent stronger than perpendicular. The compressive strength of a concrete core with a 100 mm diameter and λ=2.0 was equal to in-situ compressive concrete strength by multiplying 1.06 correction factor for damage sustained during drilling of the core.

Ramaiah , McCullough and Dossey [23] conducted very extensive study to estimate in-situ strength of concrete pavements under various field conditions and reevaluate factors that affect inaccurate estimation of in-situ pavement concrete of NSC .The use of small-diameter cores increased compressive and tensile strength by approximately 10 percent. Variability of small-diameter will be increased and can only be compensated for by increasing the number of small-diameter test specimens. The size of aggregate can have significant effects if the core diameter to nominal aggregate diameter is less than 3:1. When this is the case, strength may be significantly reduced.

Bartlett and MacGregor [7]were reanalyzed many data from previous studies about the effect of specimen diameter on magnitude of core strength The experimental data represent tests of 1080 core specimens varying from 10 92 MPa. Bartlett and MacGregor found that the effect of damage to the cut surface of the core counteracts and overwhelms any effect that might be inferred by the weakest link theory or attributed to systematic bias caused by testing procedures. The predicted average strength of a 2 in. (50.8 mm) diameter core was 94 percent of the predicted average strength of a 4-in (101.6 mm) diameter core and 92 percent of that of a 6 in.-diameter core. This mean when core diameter decrease the strength will decrease.

Viso JR and Carmona [26] conducted a study on HSC around 100 MPa compressive strength and they are particularly interested in the influence of the shape and of the size of the specimens on the compressive strength of cylinder and cub samples to perfrm stress- strain test. Large specimen resist less of stress than small one, this mean the size of cubes specimen stronger than cylinder.

Another technique for estimating compressive strength of concrete is Ultrasonic Pulse Velocity test (UPV); this is one of non-distractive concrete test method and has a wide application in rehabilitation process and investigation of the quality of concrete at the site because of the easily application, time saving, non-destructive and the low cost

One of the main goals of this research is to verify whether the standard ASTM C 42 regulation that considers a core compressive strength of HSC beam or not and the compatibility of correction factor between normal concrete and HSC . The second is to investigate usability of small size core sample in the assessment of the structures made up of HCS and establish relationship between core compressive strength and UPV values for HSC.

MATERIAL AND METHODOLOGY

The concrete has six basic components (cement, coarse aggregate, fine aggregate, water, admixture and pozzolanic materials) that shall combined together into homogenous and uniform mix to get proper property of high strength concrete. In this research, the aim was to design 100 MPa, which is given in Table 1 and it is required a lot of trail mixes and implementing precisely specification and high quality control procedure. To achieve this strength, the maximum nominal aggregate size was 9.5 mm and they are rounded to contribute both workability and increase the strength of concrete. The water binder ratio was 0.23 for 100 MPa with high fluidity.

Table 1: Mix proportions for 1 m3 of concrete

Weight (kg)	w/b	water	cement	C.A	F.A	Silica fume	Fly ash	SP 1*	SP 2*
Mix	0.23	140	470	920	669	40	160	6	3

*Note: Different types of chemical admixtures

There was a strict control of the specimen-making process, to minimize scatter in test results. It was investigated the size effect of core specimen on the value of compressive strength. The original block was designed as HSC with beam dimension of 1000 x4000 x 200 mm. Core specimens were drilled from beam block in both parallel and perpendicular to the casting directions (see Fig.1).

PVC molds have diameters (100, 75, 50, and 25 mm) with different heights (slenderness ratios (λ=l/d); 2, 1.75, 1.5, and 1) were also used and filled with the same type of concrete to compare results with the same λ core ratio that is taken from block beam parallel and perpendicular to casting direction. In addition, for control samples 9 steel cylindrical standard molds (150x300 mm) were used to assess the compressive strength of control samples at 7, 28, and 56 days.

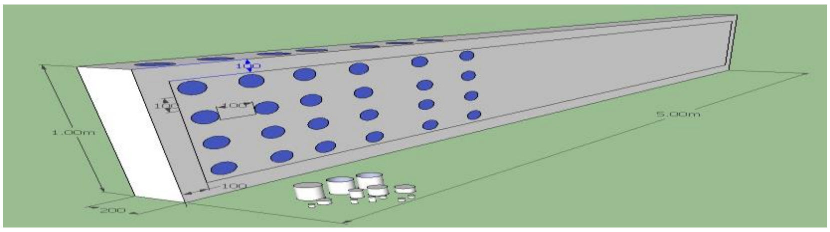


Fig. 1: The beam mould size and the core process.

The samples were divided in two groups; once filling the mould by concrete at time of casting with different size and the second group core samples were extracted by drilling process from the block beam as shown in fig.1 . The cores drilling process started after completing 28 days from time of beam casting in both vertical and horizontal direction. All extruded samples were chipping by cutter machine to adjust the slenderness of samples and then grinding machine was used to produce smooth surface without drops and cavity and to avoid deficiency in both end of samples (see Table 2). Core samples were cured in laboratory conditions up to 56 days and then tested and compared with compressive strength of the standard samples. All studies were done according to ASTM regulation.

Table 2: Dimensions of core samples and cylindrical specimens

The Diameter, mm	l/d	Number of core		Molded Samples
		PCD*	PRCD*	
25	2	4	0	5
	1.75	4	0	5
	1.5	4	0	5
	1	4	0	5
50	2	4	0	4
	1.75	4	0	4
	1.5	4	0	4
	1	4	0	4
75	2	4	4	4
	1.75	4	0	4
	1.5	4	0	4
	1	4	0	4
100	2	4	4	4
	1.75	4	0	4
	1.5	4	0	4
	1	4	0	4

The purpose of using four different core size (100, 75, 50 and 25) mm and four different length to diameter ratio (l/d) (2, 1.75, 1.5, 1) is to get better observation of energy gained by samples and behavior of high strength concrete samples when loaded and resisting applied load for different size. ASTM C 42/C42M determined the minimum core size 95 mm and the preferred l/d ratio is between 1.9 and 2.1.

RESULTS AND DISCUSSION

The beam was cast and cured in the lab condition to prevent the effect of sunlight and evaporation of water and to control the humidity. The core drilling process was started immediately after 28 days of curing duration to insure that the concrete achieved full strength. The cores with different diameters (25, 50, 75 and 100 mm) and l/d ratios (=1.0, 1.5, 1.75 and 2.0) were extracted parallel and perpendicular to the direction of casting from the beam block. All cores are separately kept in the plastic bags to keep the moisture content constant as much as possible in lab condition until the age of 56 days. The average of 6 specimens test results of core compressive strength, reference and standard specimens are given in Table 3.

Ultrasonic Pulse Velocity (UPV) values of all reference and core samples are measured by ultrasonic device in order to develop relationship between the actual compressive strength and UPV values (see Table 3).

Effect Of Core Length To Diameter Ratio (λ =l/d) On Core Compressive Strength

The lab-cured specimens exposed to water continuously available for hydration process, whereas in a structure; evaporation of water may drastically reduce water availability, preventing proper hydration and reducing strength. Thus, resulting strengths can be very dissimilar and making comparisons between the two problematic.

Table 3: The results of compressive strength and UPV values

Dia (mm)	λ =L/D	The strength of beam, (MPa)		UPV of beam (m/s)		C.F. to convert λ (l/d)=2	C.F. to convert Standard Cylinder(fc')
		Reference Sample	Core	Reference Sample	Core		
100	2	114.30	113.70	5134	5064	1	1.02
	1.75	117.90	117.00	5110	5053	0.97	0.99
	1.5	118.30	120.70	5169	5049	0.94	0.96
	1	119.90	122.30	5215	5186	0.92	0.95
75	2	114.20	112.20	5181	5144	1	1.03
	1.75	115.50	114.80	5194	5092	0.98	1.01
	1.5	119.80	115.00	5249	5203	0.97	1.01
	1	121.50	116.16	5211	5201	0.96	1.00
50	2	109.40	105.50	5227	5116	1	1.10
	1.75	110.00	108.20	5274	5195	0.97	1.07
	1.5	111.20	110.30	5328	5288	0.95	1.05
	1	112.60	112.40	5404	5368	0.93	1.03
25	2	103.60	103.30	5340	5211	1	1.12
	1.75	106.10	106.00	5473	5171	0.97	1.09
	1.5	110.20	108.80	5320	5260	0.95	1.06
	1	111.40	112.10	5199	5132	0.92	1.03
Standard Cylinder	300*150	115.9		5064		--	1

Second incompatibility is between the slenderness of the cores, (λ =L/D) ratios, and the standard cylinders. Because of this reason, the compressive strengths of cores with the same diameters vary according to their length/diameter ratios. As we can seen from Table 3 for core 100 mm diameter of the beam, when cores length decreasing, the compressive strength is increased by 3, 6 and 8 percent for λ= 1.75, 1.5 and 1 ratios, respectively, compared to λ=2, for cores drilled from beam. It means that for converting the compressive strength of a core with λ =1.0, 1.5, and 1.75 to the equivalent standard core with λ =2.0 for 100 mm diameter it should be multiplied by 0.92, 0.94 and 0.97 correction factor, respectively. As for the molded samples cured in water and compatible with the same dimension and curing duration, compressive strength increased with decreasing of the length and increment ratios were 4, 4 and 5 percent for length to diameter of 1.75, 1.5 and 1 ratios, respectively.

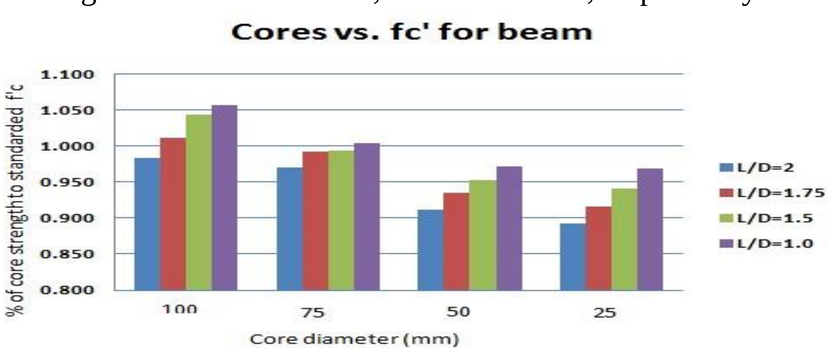


Fig. 2: The ratio of core strength to standard specimen for beam

For 75; 50 and 25 mm diameters of beam cores, with decreasing of core length, the compressive strength is also increased by 2, 3, 4 percent for 75 mm diameter; 3, 5, 7 percent for 50 mm diameter and 3, 6, 8 percent for 25 mm diameter, respectively for length to diameter of 1.75, 1.5 and 1 ratios when compared to their L/D ratio λ=2.

Similar results are reported by previous studies Ergun [13] has found that compressive strength of cores with λ =1.0 was equivalent to 92% of the compressive strength of standard cores with λ =2.0. Bartlett (1994) [6] has also suggested 0.91 and 0.87 correction factors for air-dried and soaked cores, respectively. For this study the correction factors were changed between 0.79 and 0.97 for different diameters and slenderness to be converted to an equivalent standard core specimen with slenderness ratio 2.

Fig 3 shows relationship between core compressive strength and slenderness for all core diameters, it can be concluded that with increasing of slenderness, core compressive strength decreases. The behavior of compressive strength failure has been studied extensively and Bazant [8] report that the size effect on the nominal strength of semi-brittle materials failing after large stable crack growth is caused chiefly by energy release. Kim J, Seong-Tae [18] studied the effect of the slenderness of the samples on the compressive strength and assuming that the value of slope angle was approximately selected as 45º because the confinement effects by frictional force would be negligible if the aspect ratio becomes very large. Thus, a cylinder with a slenderness L/D=λ= 1 may be able to resists higher loads than a cylinder with an aspect ratio of 2.

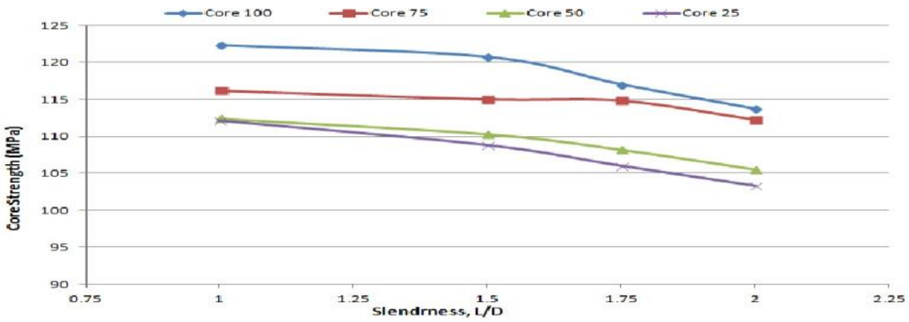


Fig. 3: Relationship between core compressive strength and slenderness for all core diameters

The Correction Factors For Beam Cores To Convert To The Standard Cylinder Strength.

As mentioned above and might be expected, the compressive strength of core concrete increased as the slenderness of cores decreased. Table.3 summarizes the correction factors to convert concrete strength to equivalent 150x300 mm standard strength with different aspect ratios.

According to the test results, most of the correction factors of HSC listed in Table 3 are more than 1 and it was changed between 1.0 to 1.12 for different core diameters and slenderness. For example, for 100 mm diameter with slenderness 2 it was 1.02 and with decreasing of slenderness it reduced to 0.95 for slenderness 1. As for the 75 mm diameter cores, for all slenderness correction factors were lower than those of 100 mm diameter cores and the same trend was observed for this group too, it was decreased with the reduction of slenderness and it was changed between 1.03 and 1.0. Bartlett and MacGregor [7] also reported that the compressive strength of a concrete core with a 100 mm diameter and λ=2.0 was equal to in-situ compressive concrete strength by multiplying 1.06 correction factor for damage sustained during drilling of the core.

50 and 25 mm core's correction factors are increased when compared with 75 and 100 mm diameter's correction factors. Even though the slenderness has effect on the 50 mm core correction factor but it nearly lost its effect on 25 mm core correction factor. This may be due to the lower concrete volume of small cores which is between 64 and 128 times smaller than the largest one. It can be concluded that most correction factors of all samples was higher than 1 and this was mentioned in ACI-C42 about the correction of HSC but the code does not mention exact value. The correction factors are increase as the cores diameter decrease .The small cores sizes (25&50 mm) are applicable to be used in estimation of the HSC and the standard deviation was between 2.4 to 1.9 and these results are acceptable to avoid damaging causes by use of bigger core size.

The small core size is very useful and practical way to estimate the compressive strength of concrete without harmful to concrete element. The correction factors are decreased by 1.0 percent to 3.0 percent as slenderness ratio (l/d) of samples decrease for certain diameter. The difference for beam of HSC was between 0.98 and 0.89 percent for cores between 25 and 100 mm diameters with the slenderness $\lambda=2$ for this study (See Fig. 2).

Effect of Diameter size On Compressive Strength And UPV Values

The largest sample of l/d=2 is one hundred twenty eight times bigger than the smallest samples by volume. The ratio between sample dimension and maximum aggregate size varies between 2.70 and 10.31 for 25 and 100 mm diameter respectively. An inverse relationship between strength and specimen size is typical of concrete samples[10] and this feature is evident and meaningful from the results given in Table 4.

It is clear from the results in Table 4 that the reference samples and cores showing same trend of diameter effect. The 100 mm diameter reference samples are stronger than any cored samples. However, this difference is not very significant for all samples.

UPV values are also increased with the decreasing of the both molded samples and core sizes, except 25 mm diameter core samples.

Table 4: The compressive strength and UPV values for different samples slenderness ratio

Slenderness ratio (λ)		The strength of beam (MPa)		UPV of beam (m/s)	
	Dia (mm)	Reference Sample	Core	Reference Sample	Core
2	100	114.3	113.7	5134	5064
	75	114.2	112.2	5181	5144
	50	109.4	105.5	5227	5116
	25	103.6	103.3	5340	5211
1.75	100	117.9	117	5110	5053
	75	115.5	114.8	5194	5092
	50	110	108.2	5274	5195
	25	106.1	106	5473	5171
1.50	100	118.3	120.7	5169	5049
	75	119.8	115	5249	5203
	50	111.2	110.3	5328	5288
	25	110.2	108.8	5320	5260
1	100	119.9	122.3	5215	5186
	75	121.5	116.16	5211	5201
	50	112.6	112.4	5404	5368

	25	111.4	112.1	5199	5132

The Effect Of Coring To The Casting Direction For HSC Beam

The results of the core test for perpendicular and parallel to casting direction for 100 and 75 mm diameter with slenderness ratio of 2 are presented in Table 5.

It appears that, on average, the parallel cored samples are slightly stronger than the perpendicular cored ones; this difference was 1.14 percent for 100 mm diameter and 2.7 percent for 75 mm diameter. Some investigators have observed similar results and they reported that the strength of cores that casted parallel to casting direction were more than that of perpendicular to casting direction by 8% to 12 % [25].Bartlett and Macgregor [4] for the only concrete mix containing fly ash and air-entraining admixtures, the cores with axes parallel to the direction of casting are 14 percent stronger than the cores with axes perpendicular to the direction of casting .

Table 5: The effect of coring direction to the casting direction for HSC beam.

Dia (mm)	Direction	l/d	Test Age (Days)	Core strength (MPa)	UPV (m/s)	Stand.Devi. (%)	The difference (%)
100	P	2	56	115.0	5117	1.2	1.14
	R	2	56	113.70	5064	1.14	
75	P	2	60	115.30	5131	1.3	2.7
	R	2	60	112.2	5144	2.4	

P : Parallel to casting direction

R : Perpendicular to casting direction

The Relationship Between Strength Of Concrete And UPV

UPV value increase very rapidly at early age and in a very short time it reaches its plateau value relative to strength[12] .UPV is also influenced by many variables, such as moisture content, aggregate type, mixture proportions, age of concrete, and others but the factors significantly affecting the concrete strength might have little influence on UPV. Therefore, each type of concrete is unique and there exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete by UPV.

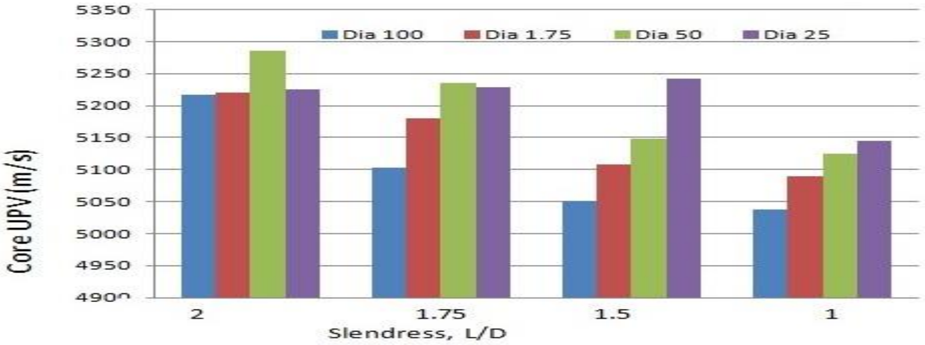


Figure 4: Effect of slenderness (L/D) ratio with UPV results

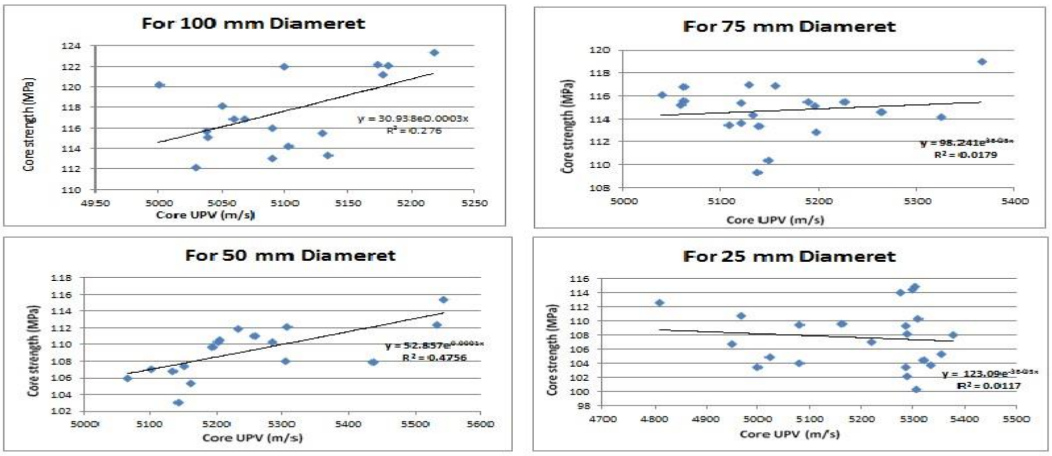
Many studies suggest UPV as measure of concrete quality assessment. Fig 4 shows a relationship between slenderness of core specimen and corresponding UPV for all concrete specimens cored from beam. As figure clearly depicts UPV values in a range of 5000–5300 m/s, that is suggesting a very good quality of HSC.

The results are presented in Fig 4 that UPV is affected by aspect ratio of cores. The value of UPV tends to increase as L/D decreases. It is observed that UPV values have changed with the variability of diameter. The standard deviation of UPV values for 100, 75, and 50 mm diameters are within acceptable range but 25 mm diameter core samples has a large variety in the results (see Fig 5-d). Thus it gives large standard variation so this diameter is not applicable to be used in determination of UPV to evaluate the concrete quality.

According to previous studies the compressive strength and UPV values are related by the

The Fig. 5 shows four different correlation when the core diameter change the curve of scattered results will be changed as follow:

(a) (b)



(c) (d)

Figure 5: The relationship between the strength of cores with UPV for different core size for beam.

$$f100 = 30.938 * e0.0003x \quad (2)$$

$$f75 = 98.241 * e3E - 5 * x \quad (3)$$

$$f50 = 52.86 * e0.0001 * x \quad (4)$$

$$f25 = 123.09 * e - 3E - 5 * x \quad (5)$$

Where fc is the compressive strength (MPa), and x is the UPV value (m/s).

The R^2 values were 0.27, 0.018, 0.47 and 0.012, for 100, 75, 50 and 25 mm , respectively, it can be said that between 95 and 97% of the variation in values, the core compressive strength can be accounted for by exponential relationship with UPV (see Fig. 5) The results for all diameters except 25 mm, agreed with the model Eq. (1) of Tharmaratram[21], Demirboga [12]and Omer[22]. For 25 mm, the core compressive strength yielded 64% of the variation in observable values by exponential relationship with UPV values.

CONCLUSIONS

The study conducted on HSC cored from a beam block with different diameters and slenderness aspect ratio. Based on the results of this research, the following conclusions could be drawn:

1. The compressive strength of both reference samples and cores increased with the decrease of λ ratio.
2. For converting the compressive strength of a core with λ =1.0, 1.5, and 1.75 to the equivalent standard core with λ =2.0 for 100 mm diameter it should be multiplied by 0.92, 0.94 and 0.97 correction factor, respectively.
3. The correction factors to convert core strength to equivalent 150x300 mm standard cylinder strength changed between 0.95 and 1.12 for different core diameters and slenderness ratios.
4. The correction factor to convert the core compressive strength to standard cylinder strength reduced with the slenderness of core but increased with decrease of core diameter.
5. The core's compressive strength of all groups were lower than those of water cured samples that have the same dimension, slenderness and curing duration.
6. It appears that, on average, cored samples parallel to cast direction are slightly stronger than the perpendicular cored ones; this difference was 1.14 % for 100 mm diameter and 2.7 % for 75 mm diameter.
7. An exponential relationship between UPV and core compressive strength for 100, 75 and 50 mm diameter provided an adequate approximation to compare the two, with R2 values in the range of 95–97%. However this value was 64% for 25 mm diameter.

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