

MECHANICAL BEHAVIOR OF FLOWING CONCRETE AND EARLY STRENGTH CONCRETE WITH THE ADDITION OF TYPE D AND F ADMIXTURES

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Flowing concrete (FC) and self-compacting concrete (SCC) that are produced with admixtures can be a solution to the complexity of construction problems. Self-compacting concrete is a special type of flowing concrete, but flowing concrete is not necessarily self-compacting concrete. This paper investigates the adding type D and F admixtures with andesite stone as the potential local coarse aggregate materials which were abundantly available for flowing concrete and early strength concrete (ESC) performance. This study has two test categories: fresh concrete and hardened concrete. The fresh concrete category includes slump, slump flow, and T_{500} tests. Meanwhile, the hardened concrete category includes compressive, splitting tensile, and flexural strength tests. The experimental results indicated that the admixture type F dosage of 1.0%, 1.55% and 1.75% cement weight can enhance the compressive strength by 3.88%, 5.82% and 9.71% respectively. The combination of type F and D admixtures with dosage of 0.15% and 0.2% cement weight show a reduction in compressive strength by 12.62% and 3.89% respectively. On the other hand, both combination of admixtures can reach better performance on the final setting time which lead the slows the hydration process and provides adequate time to put concrete to the formwork. The results also show adequate correlations between compressive strength and the flexural strength. Furthermore, a prediction model is established the ratio of both value (f_{tsp}/f'_c) based on the regression analyses, while it decreases obviously with the increase of compressive strength. It can be clearly that the ratio is strongly affected by compressive strength.

Keywords: admixtures, retarder, flowing concrete, early strength concrete

1 INTRODUCTION

Aggregate is considered as the main constituent of concrete which accounts for 60 to 80 % of the volume and 70 to 85 % by the weight of concrete. The coarse aggregate is a part of the aggregate that contributes the most significant volume (31-50% of the concrete composition).

Aggregates are essential constituent materials for the concrete construction industry. The proper selection of coarse aggregate can influence the compressive strength of concrete. Their mechanical properties control the applicability of coarse aggregate. The most common igneous rock that is used to substitute coarse aggregate for applied in concrete, road, and railway construction is andesite stone [1]–[8].

The complexity of construction, such as mass concrete and heavy reinforcement area of the structure, brings a problem due to the flowability of normal concrete which can affect the concrete durability. Nowadays, flowing concrete (FC) and self-compacting concrete (SCC) that are produced with several admixtures can be a solution to this problem which have the advantages of high fluidity, little or no compaction without segregation [8]–[13]

According to The European Guidelines[14], self-compacting concrete can be defined as concrete that can flow under its weight, fill the formwork even in heavy reinforcement, without compaction, and can maintain the homogeneity of the concrete. The characteristic of self-compacting concrete can be determined by several critical factors such as flowability, viscosity, passing ability, and segregation. All characteristics must be prescribed if specifically required. On the other hand, according to ASTM C-1017[15], flowing concrete can be defined as concrete with a slump value of more than 19 cm. Self-compacting concrete is a particular type of flowing concrete, but flowing concrete is not necessarily self-compacting concrete. Proper mix design, the dosage of admixture, binder material, and addition of natural fiber are essential to optimize the performance of both flowing and self-compacting concrete [13],[16]–[19]

High-performance concrete (HPC) can be defined as concrete with better properties and constructability than normal concrete. Several characteristics that should be required for determining HPC include enhanced durability, intensified engineering properties, and other enhanced properties [20],[21]. Utilizing superplasticizers and low water-cement ratios of 0.20 to 0.45 are typically applied to produce HPC. One type of HPC is early strength concrete (ESC) or a type of concrete that can reach the specified criteria for compressive strength > 20 MPa to 41 MPa at 3 to 18 hours, or 1 to 3 days after site-pouring [22]. ESC is used for precast concrete, prestressed concrete, high-speed cast in situ, rapid elements production, and other uses. Generally, it takes 7 to 14 days for the concrete to fully harden and reach a minimum compressive strength of 0.7 to 0.85 f'_c [23]. ESC concrete, in its use, achieves high strength in the early stages after the setting time occurs so that the processing time is faster and becomes economical and practical. At the same time, the ESC innovation uses a sustainable concept so that it can be used sustainably and can be used by future generations.

The following points need to be considered to obtain a concrete mix with ESC: coarse aggregate is limited to approximately 50% of the solid volume, the amount of fine aggregate is limited to approximately 40% of the mortar volume, the water ratio is maintained at a level of approximately 0.3, the use of superplasticizers in concrete mixtures to obtain a high level of workability while simultaneously suppressing the value of the water ratio, and adding a filler in the form of silica fume to increase the durability and compressive strength of the concrete: Coarse aggregate is limited to approximately 50% of the solid volume, the amount of fine aggregate is limited to approximately 40% of the mortar volume, and the water ratio is maintained at a level of approximately 0.3, the use of superplasticizers in concrete mixtures to obtain a high level of workability while simultaneously suppressing the value of the water ratio, and adding a filler in the form of silica fume to increase the durability and compressive strength of the concrete [24].

Several admixtures can produce flowing concrete and ESC: Accelerating and Water Reducing Admixture and High Range Water Reducing Admixture [25]. In general, the increase in superplasticizers, such as type F admixture dosage, can escalate workability and accelerate the hydration process of concrete, which can cause bleeding and segregation [19],[26],[27]. Therefore, it may cause problems if applied to flowing concrete. Moreover, retarders such as type B and D admixture, which mainly extend the setting time for concrete (initial and final), slow the hydration process and provide adequate time to put concrete into the formwork. On the other hand, the compressive strength of concrete with a retarder is lower than that of concrete without a retarder [28].

The effects of suitable admixture dosage still need further investigations to maintain the workability and consistency for reaching flowing concrete and early strength concrete performance. In this study, workability was measured under increased admixtures dosages of 1.0%, 1.55%, 1.75% for type F admixture and 0.15% and 0.2% for combination type D and F admixture. Thus, the impact of all admixtures on fresh and hardened concrete were measured.

2 MATERIALS AND METHODS

2.1 Materials

The physical properties of fine and coarse aggregates are listed in Table 1. The fine aggregate (FA) is river sand and considered a medium type with a fineness modulus of 2.89, while the coarse aggregate (CA) is identified as an andesite stone, Ladung Stone, is a local construction material that can be easily found in South Kalimantan for construction needs. Based on ASTM C33/C33M [29], the maximum coarse aggregate abrasion value used in concrete is 40%; thus, Ladung as coarse aggregate satisfies this limit.

Table 1. Fine and coarse aggregate properties

Properties	Aggregates	
	Fine Aggregate (FA)	Coarse Aggregate (CA)
Type		
Name	Barito	Ladung
Water content	2.28%	1.25%
Specific gravity	2.48	2.71
Fineness modulus	2.89	7.20
Size (mm)	<4.75	±10-20
Abrasion value	-	13.8%

This study's cement type is Portland Composite Cement (PCC), with a specific gravity of 3.16. PCC is a blended hydraulic cement including mixed ordinary cement-based and pozzolanic materials. The concrete mix design shown in Table 1 includes admixture type F (high range water reducer) and type D (water reducer retarder) as additives mainly used to increase workability, reduce water intake, and delay concrete setting time [25].

In Table 2, mix design of concrete mixture, specimens are named based on the content of the admixture, e.g., V0VZ0 is described with V= admixture type F, 0=percentage of admixture type F, VZ=admixture type D, and the last 0=percentage of admixture type D. V0VZ0 is the benchmark with 0% admixture type F, and 0% admixture type D. The concrete compressive strength design is 40 MPa. The mix design proportions are based on EFNARC [14] for Self-Compacting Concrete (SCC) requirements, adjusting to the w/c ratio. The w/c ratio is changeable to accommodate admixtures.

Table 2. Fine and coarse aggregate properties

Specimens	Concrete compositions per m ³					
	FA (kg)	CA (kg)	PCC (kg)	Water (litre)	Admixture	
					Type F (litre)	Type D (litre)
V0VZ0	826.40	1051.79	485.26	146.55	0	0
V1VZ0	826.40	1051.79	485.26	134.29	4.85	0
V1.55VZ0	826.40	1051.79	485.26	131.58	7.52	0

Specimens	Concrete compositions per m ³					
	FA (kg)	CA (kg)	PCC (kg)	Water (litre)	Admixture	
					Type F (litre)	Type D (litre)
V1.75VZ0	826.40	1051.79	485.26	130.59	8.49	0
V1.55VZ0.15	826.40	1051.79	485.26	129.77	7.52	0.73
V1.55VZ0.20	826.40	1051.79	485.26	129.50	7.52	0.97

2.2 Methods

This study has two test categories: fresh concrete and hardened concrete. The fresh concrete category includes slump, slump flow, and T_{500} tests. Meanwhile, the hardened concrete category includes compressive, splitting tensile, and flexural strength tests. The slump, slump flow, and T_{500} tests are conducted to check the characteristics of concrete flow on whether they are related to high-flowability concrete. The concrete compressive strength observations are at one day, three days, seven days, 14 days, and 28 days, while the concrete tensile strength is at 28 days. Each observation will use three samples for each variation. As for the concrete flexural strength, observations are at 28 days with two samples for each variation. The specimen size for compressive and splitting tensile tests is a cylindrical PVC pipe of 11 cm in diameter and 22 cm in length. It is by BSN [30] on how to test the compressive strength of concrete with a cylindrical test object where the length over diameter (L/D) ratio ranges from 1.8 to 2.2. For the flexural strength test, use beams size of 50x10x10 cm.

For investigating the flexural strength of each specimen used a flexural strength test machine where the test object is placed on the loading frame with support joints at one end and rollers at the other. Loading was performed using a two-point load in one-third of the span, 150 mm. Loading is done by pumping the hydraulic pump, which is forwarded to the hydraulic jack, and the load given through the hydraulic jack can be read by the load cell and recorded by the load indicator. Data obtained from flexural testing includes: maximum load and crack pattern.

3 RESULTS AND DISCUSSION

3.1 Test of Fresh Concrete

3.1.1 Setting Time Observation

Further investigations have examined the effect of admixture type F (high range water reducer) and type D (water reducer retarder) on the setting time by using cement paste and admixtures on Vicat Apparatus. The initial and final setting times for six concrete variations are shown in Fig. 1. Each variation is with 500 gr of cement weight.

The initial setting time is achieved when the concrete paste loses its plasticity, while the final setting time is when it is hardened. The initial setting of the concrete paste occurs when the penetration result is greater or equal to 25 mm of the experimental setting time. Except specimen V0VZ0 as normal concrete without admixtures, the water is reduced by 30% when adding admixtures to ensure the appropriate mixture dilution. When adding an admixture, the optimum water reduction is 30%, in line with Syafrudin [31].

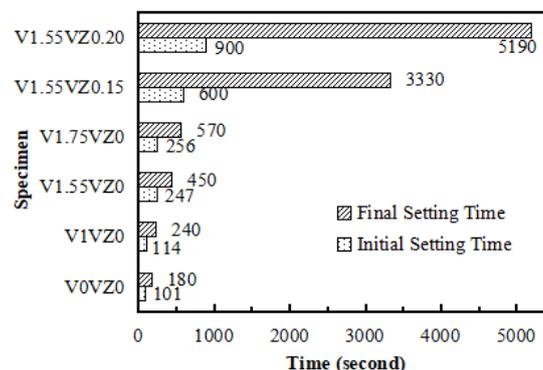


Fig. 1. Setting time of fresh concrete

In Fig. 1, adding admixture, i.e., type F and type D, proved effective in slowing down the setting time of the mixture. Especially on the effect of admixture type D dosage of 0.15%, it can slow down the initial setting time to more than 100%. The final setting time is also much slower with the addition of admixtures, which prevents the hardened concrete from being tested for day 1.

The addition of admixture type F in the concrete mixture has a function of achieving flowing concrete properties, but it rapidly hardens so that adding a water reducer and retarder is needed, as investigated where the addition of admixture type D slows down the setting time.

3.1.2 Slump Test, Slump Flow and T_{500} test

The Slump Test has been performed to examine the concrete mixture workability for six variations and whether it satisfies the Slump requirements for flowing concrete of 190 mm. This requirement is based on ASTM C1017/C1017M [15] for flowing concrete with the addition of admixtures.

Specimens except V0VZ0, as shown in Fig. 2, achieve the flowing concrete requirement. Adding the admixture type F is expected to escalate its flowability properties—while the addition of type D admixture with a dose of 0.15% reduces the slump to 4% but increases when the dose is up to 0.20%. It can be said that, in general, admixture type D does not affect the increase in the slump value after admixture type F is added to the concrete mixture.

This study refers to flowing concrete, but it can meet the two characteristics of Self Compacting Concrete (SCC) as a comparison. It is said to be SCC if four characteristics are fulfilled: filling ability, flowability, passing ability, and segregation. The slump flow is a test method to evaluate the filling ability characteristics by the total spread of fresh concrete, while T_{500} assesses flowability characteristics using fresh concrete flow time [14]. Both slump flow and T_{500} tests can be achieved in one experiment, as shown Fig. 2.

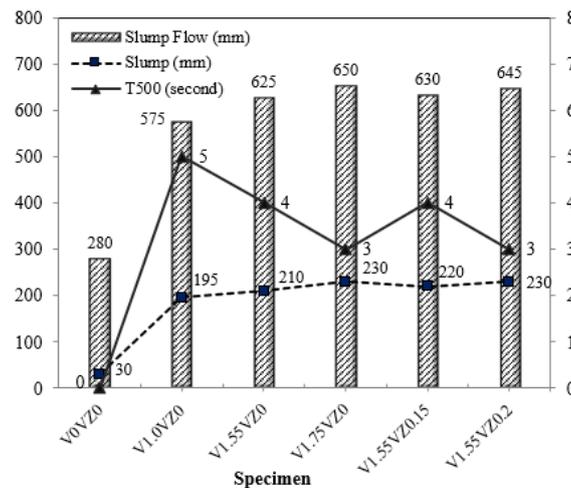


Fig. 2. Test result for slump test, slump flow test, and T_{500} for all specimens

Based on use EFNARC [32] and [14], specimens with admixtures, as shown in Fig. 2, satisfy the acceptance criteria for SCC with slump flow properties ranging from 520 mm to 700 mm, and T_{500} properties typically about 2 to 5 seconds. In Figure 2, adding admixtures to the concrete mixture successfully escalates the slump flow value and lowers the T_{500} value. Noted that V0VZ0 flow does not satisfy the T_{500} requirement; the T_{500} value is zero. It is also observed that increasing the dosage of either admixture type F or type D will not give a significant rise in slump flow or an extreme drop in T_{500} value. The dosage and type of admixture will function differently for initial and final setting times.

3.2 Test of Hardened Concrete

It should be emphasized that this experimental phase analyzes the hardened concrete performance for determining the effect of andesite stone as coarse aggregate and the effect of admixture type F and type D dosage in terms of the early strength and compressive strength requirements. The following Fig. 3 is briefly the performance of compressive strength with utilizing potential local material "Ladung Stone" as coarse aggregate from Kotabaru, South Kalimantan, with the variation of admixtures dosage for producing flowing concrete with early strength performance.

3.2.1 Compressive and Splitting Tensile Strength

As expected, all specimens' compressive strength gradually increased with the age of curing days. Moreover, Fig. 3 shows that the dosage of admixture type F and type D used and the proper choice of coarse aggregate is capable of maintaining flowing concrete strength.

For identifying flowing concrete performance, ASTM-C1017[15] also requires that the minimum compressive strength achieved at 28 days is 90% of the compressive strength design. It can be said that the minimum compressive strength required for flowing concrete was between 36 MPa or 90% of the compressive strength design. Fig. 4 depicts the V0VZ0 specimen as a conventional concrete and a control specimen.

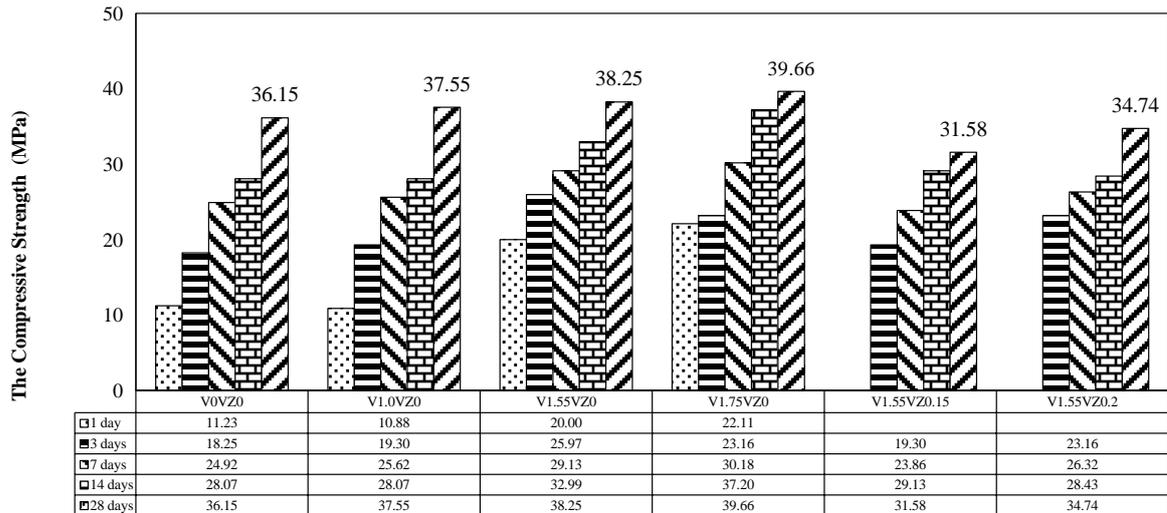


Fig. 3. The compressive strength test result for 1,3,7,14 and 28 days

It can be observed that the dosage of the admixtures can affect the flowing concrete performance. This statement indicates that increasing the admixture type F dosage of 1.0%, 1.55%, and 1.75% cement weight (V1VZ0, V1.55VZ0, and V1.75VZ0 specimens) can enhance the compressive strength of flowing concrete. On the other hand, combining two admixtures in the composition of concrete admixture type F and type D, namely V1.55VZ0.15 and V1.55VZ0.20 specimens, can alleviate and uncategorized as the flowing concrete.

Concrete can be said to have an increase in early strength when the concrete reaches 50% of the design compressive strength at 24 hours, with a water-cement ratio ranging from 0.3 to 0.4 [23]. The compressive strength of concrete of all specimens with admixture type F and type D are shown in Fig. 3. The results presented in Fig. 4 reveal that the admixture type F could influence the performance of concrete in terms of early strength concrete. The compressive strength of V1.55VZ0 and V1.75VZ0 specimens, which added 1.55% and 1.75% of admixture type F in mixture composition, can meet the compressive strength required for early strength concrete based on ACI [23]. Moreover, it can be approved that the specimen without utilizing an insufficient dosage of admixture type F cannot reach the criteria of 50% of design compressive strength at a day age for early strength concrete.

Fig. 4 also investigated the effect of combination admixture in concrete (type F and type D admixtures) for both last specimens, V1.55VZ0.15 and V1.55VZ0.2.

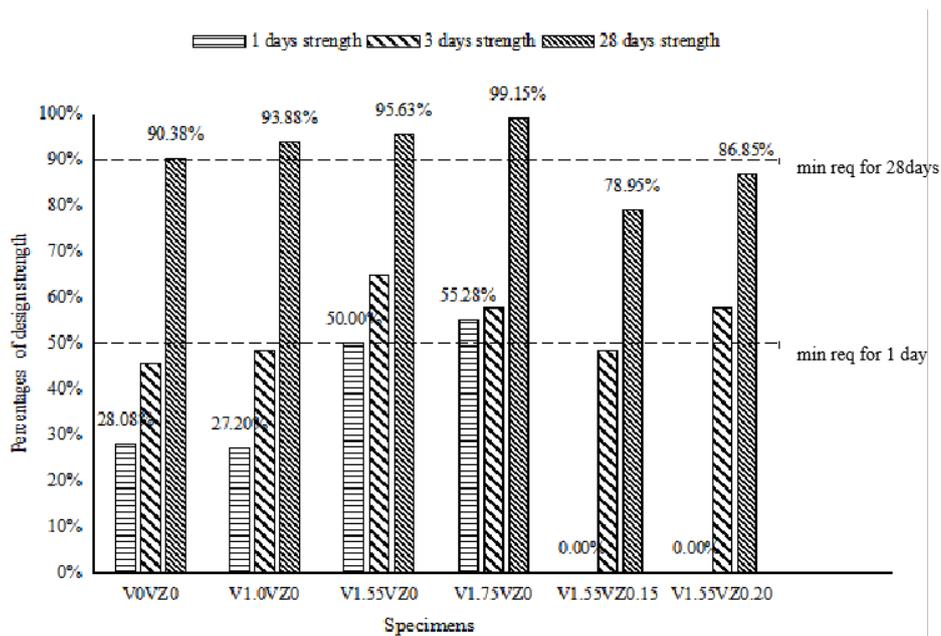


Fig. 4. The compressive strength result compared with the design compressive strength

3.2.2 Relationship between compressive and splitting tensile strength

A set of regression analyses was carried out to evaluate the ratio of splitting tensile to compressive strength (f_{tsp}/f'_c), and the results are summarized in Fig. 5 where f_{tsp} is the splitting tensile strength, and f'_c is the compressive strength.

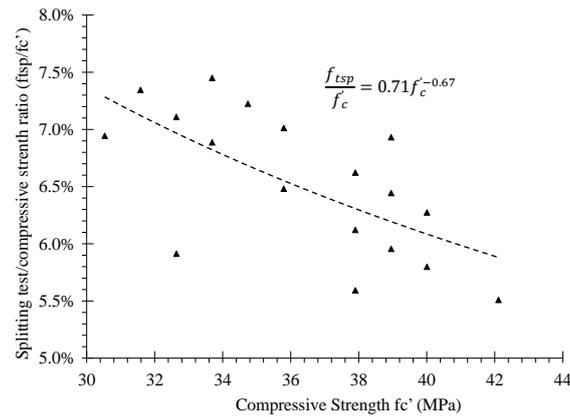


Fig. 5. Relationship between compressive strength and ratio of splitting tensile strength

The ratio of both values (f_{fsp}/f_c') decreases with increasing compressive strength. It can be clear that the ratio is strongly affected by compressive strength. This experiment's findings are from previous research [33]. The ratio of splitting tensile strength to compressive strength in this study range from 6% to 7%. Generally, it ranges from 6% to 20% [34].

3.2.3 Flexural strength

In this experiment, the flexural strength is determined by testing beam specimens with dimensions of 50x10x10 cm at the age of 28 days using a third point loading method based on ASTM C78/C78M [35] which can be depicted in Fig. 6. All beam specimens suddenly fracture at peak load (Fig. 7). According to ASTM C-78, the flexural strength of the beams can be calculated if the fracture begins at the tensile surface within the middle third of the span length.



Fig. 6. Test flexural strength set-up



Fig. 7. Crack pattern of flexural strength test of specimens

3.2.4 Relationship between compressive and splitting tensile strength

Table 3 presents the relationship between compressive and flexural strength of the conventional concrete using various equations. A comparison of the measured data from current study with the several predictions models is presented in Fig. 8. Comparison predicted flexural strength models and actual flexural test of specimens. It shows that the result of the flexural strength obtained from all specimens are higher than prediction models.

Almost approach model predictions tend to underestimate the flexural strength of all specimen data. One of approach model engineered cementitious composites concrete [36] indicates a higher value with approximately 30 %-70% if compared to the measured data.

Table 3. Fine and coarse aggregate properties

Reference	Equations
Choucha et al. [36]	$1.4f_c^{0.7}$
Ahmed et al. [37]	$0.3f_c^{0.5} \leq f_r \leq f_c^{0.5}$
Legeron & Paultre [38]	$0.68f_c^{0.5} \leq f_r \leq 1.2f_c^{0.5}$
ACI 363 [39]	$f_r = 0.94f_c^{0.5}$
Mindess et al. [40]	$0.11f_c \leq f_r \leq 0.23f_c$
Selim [41]	$f_r = 0.034f_c^{1.286}$
Chhorn et al. [42]	$0.678f_c^{0.605}$

Therefore, it is necessary to develop a correlation model between flexural strength and compressive strength of flowing concrete with addition admixture.

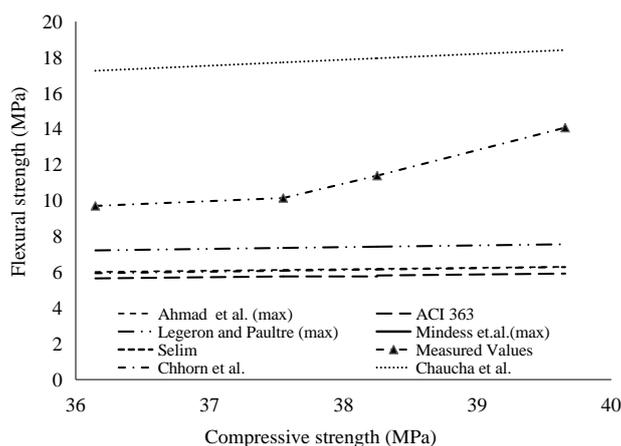


Fig. 8. Comparison predicted flexural strength models and actual flexural test of specimens

4 CONCLUSION

Based on the results and discussions in previous sections, it is concluded that:

1. Adding admixture types D and F will increase the initial and final setting time of fresh concrete compared with the benchmark specimen without admixtures. It is also observed that the characteristic of fresh concrete becomes flowing concrete where it satisfies two of four categories of Self Compacting Concrete (SCC) based on EFNARC [14],[32] when adding both admixtures.
2. The experimental results indicated that the admixture type F dosage of 1.0%, 1.55% and 1.75% cement weight can enhance the compressive strength by 3.88%, 5.82% and 9.71% respectively. The combination of type F and D admixtures with dosage of 0.15% and 0.2% cement weight show a reduction in compressive strength by 12.62% and 3.89% respectively.
3. The compressive strength value strongly influences the ratio of splitting tensile strength to compressive strength. The ratio of splitting tensile strength to compressive strength in this study range from 6% to 7%. Generally, it ranges from 6% to 20% [34].
4. A relationship between compressive and flexural strength was developed from the measurement data, which provided that six various equations underestimate flexural strength. On the other hand, this value was slightly lower than the range of that engineered cementitious composite based on [36].

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