ISSN 1392–3730
JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
http:/www.vtu.lt/english/editions
2003, Vol IX, No 4, 271–279

PROPERTIES OF FRESH POLYPROPYLENE FIBRE REINFORCED CONCRETE UNDER THE INFLUENCE OF POZZOLANS

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Received 23 March 2003; accepted 27 Jun 2003

Abstract. This paper summarises experimental results of some fresh concrete tests. Polypropylene fibres were added to the concrete mix to produce fibre reinforced concrete. Pozzolanic materials, including pulverised fly ash and silica fume, were used as partial replacement of cement, and their effects on the fresh fibre concrete were reported. Test results showed that the polypropylene fibre reduced the concrete workability significantly by thixotropic effect and decreased the setting time. Substitution of pozzolans also greatly affected the properties. The presence of fly ash increased the workability and setting time but in the presence of silica fume a reverse trend was observed. Empirical equations were proposed.

Keywords: fresh concrete, cement, fly ash, pozzolan, silica fume.

1. Introduction

The use of high strength concrete in the construction industry is very popular at present. One major drawback is that high strength concrete is relatively brittle with low tensile strength and strain. Its failure may be sudden particularly when subjected to earthquake, blast or impact load. An ideal solution to overcome this disadvantage of high strength concrete is to incorporate fibres in the concrete design so as to give a more ductile material [1, 2]. Addition of discontinuous fibres can also be used as secondary reinforcement for controlling cracks [1].

A lot of research in the area of reinforced fibrous concrete has been done in the past. Some of the fibres which have been used extensively today include carbon, glass, natural fibres, polypropylene and steel; the last two are the most widely used in conventional concrete [3]. Polypropylene fibres are more resistant to decay from the alkaline environment within concrete than the natural fibres and normal glass fibre. Generally, the main concern in using the fibres is the high cost. However, polypropylene fibres can be produced at a more economical cost in oil producing countries [4]. Considering the economical and corrosive reasons, polypropylene fibres will be employed in the near future [5]. As there is limited research on polypropylene fibres than steel fibres, they were thus chosen in this study.

As pointed out by Hannant [6], the major use of polypropylene fibres has been in the bulk concrete products rather than for thin sheet materials. The most widely used fibre is fibrillated polypropylene twine, typically chopped to 40 mm lengths and included at 0,44 % by volume in the precast concrete products. The main benefit endowed on the concrete by polypropylene fibres is additional impact strength and large energy absorption characteristics but there is unchanged in tensile and bending strength. Balaguru *et al* [7], Muliscs [8] and Hannant [9] also stated that when fibres were added to the concrete, a serious loss of workability occurred.

According to ACI Committee 544 [10], partial replacement of cement by pozzolans, such as pulverized fly ash (PFA) and silica fume (SF) can offer a great contribution in the fibre reinforced concrete (FRC). They can improve the mechanical properties either in the fresh state and hardened state. It also states that pozzolans can be used in fibre concrete to reduce the relatively high cement contents in conventional concrete.

Generally, use of PFA in concrete mix increases the initial setting time (I_{st}) and the final setting time (F_{st}). The presence of PFA can reduce the quantity of water that is required to produce the target slump. Besides, due to the fineness and rounded shape of the fly ash particles, the cohesion and workability of the concrete can be improved. Also the concrete containing fly ash reduced the segregation and bleeding compared to control concrete without fly ash [11].

Since the SF particle is ultra-fine, it becomes a filler to fit into the spaces between the cement grains, while the sand fills the space between the particles of coarse aggregates and the cement grain fills the spaces between the sand grains. This can increase the internal cohesion of fresh concrete. As a result, the slump is reduced [12]. Also the initial setting time and final setting time are decreased.

In order to verify the effects of fly ash and silica fume on polypropylene fibre reinforced concrete, an experimental programme was proposed at the City University of Hong Kong. It aims at investigating the interaction between polypropylene fibres and pozzolans. The mechanical properties of FRC in fresh state, such as workability and setting time with and without pozzolans were examined by slump, Vebe time, unit weight and penetration resistance tests.

2. Details of experiments

Other than the basic materials in manufacturing concrete, three additional materials employed in this project are polypropylene fibres, PFA and SF. Polypropylene fibres are inert and impervious to attack and they do not absorb water. They are also resistant to chemical attack. Therefore they are suitable to be used in Portland cement concrete [5, 13]. The polypropylene fibres used in this study were produced from W. R. Grace (Hong Kong) Limited. Some basic properties are listed in Table 1.

PFA is a by-product from coal burning process in power generating plants. It is a residue of combusting fine coal. The major components of fly ash include alkali oxides, alkaline earth oxides, alumina oxide, silica oxides and iron oxides [14, 15]. Silica fume is a by-product from the operation of electric arc furnace which is used to reduce high purity quartz with coal in the production of elemental silicon and ferrosilicon alloys. It consists of extremely small spherical particles of amorphous silicon dioxide that are collected from the furnace gases.

In order to determine the mechanical properties of fresh concrete, four different mixes were designed. They included ordinary Portland cement concrete (Mix C), polypropylene fibre reinforced concrete (Mix CP),

Table 1. Properties of polypropylene fibres [16]

Specific gravity	0,91
Absorption	None
Modulus of elasticity	3500 N/mm^2
Melting point	160 °C
Ignition point	590 °C
Alkali, acid, salt resistance	High

polypropylene fibre reinforced fly ash concrete (Mix CPF) and polypropylene fibre reinforced silica fume concrete (Mix CPS). The mix proportions of the four mixes were very similar. Three mixes (Mixes CP, CPF and CPS) were made using polypropylene fibres containing about 0,2 % by concrete volume. Mixes CPF and CPS contained 10 % fly ash and 10 % silica fume respectively to replace the same amount of the weight of cement. Also the same amount of superplasticiser (Daracem 100) was added to each mix to improve the workability (Table 2).

The quantities of materials required for each batch were calculated according to the design mixes. Mixing of concrete was done in a rotary mixer according to BS 1881: Part 125:1986. Freshly mixed concrete was tested for slump [17], Vebe time [18], air content [19], and penetration resistance [20]. According to ASTM C403-92 [20], the initial and final setting times are corresponding to a penetration resistance 3,5 N/mm^2 (500 psi) and 27,6 N/mm^2 (4000 psi) respectively. Therefore the initial setting times and final setting times of different mixes were determined.

2.1. Slump test

It is used to determine the workability of fresh concrete. The equipment and the procedure for slump test is very simple and a common method. It includes a tamping rod, a metal slump cone and an non-absorbent steel base plate. The test and procedures are complied with BS 1881: Part 102:1983 (Method for determination of slump) [17].

Table 2. Mix proportion of each mix

Mix type / Concrete components (kg/m^3)	Mix C Ordinary portland cement concrete (OPC)	Mix CP Fibre reinforced concrete (PFRC)	Mix CPF Fibre reinforced fly ash concrete	Mix CPS Fibre reinforced silica fume concrete
Cement	360	360	324	324
Coarse aggregates 20 mm 10 mm	 720 400	 720 400	 720 400	 720 400
Fine aggregates	700	700	700	700
Water	180	180	180	180
Polypropylene fibre	–	2,58	2,58	2,58
Fly ash	–	–	36	–
Silica fume	–	–	–	36
Daracem 100 (5cc./kg)	1800	1800	1800	1800

Note: The amount of Daracem 100 is dependent on the cement used. 5cc. of Daracem 100 will be used per 1kg of cement.

2.2. Vebe time test

The Vebe test is also used to measure the degree of workability. It includes a Vebe apparatus and a stop-watch. The test and procedures are complied with BS 1881: Part 104:1983 (Method for determination of vebe time) [18].

2.3. Air content test

This test is used to measure the total air content of fresh concrete and to test whether the concrete is fully compacted. The pressure method is applied because it is the most dependable and accurate method which is based on the relation between the volume of air and the applied pressure (at a constant temperature) given by Boyle's law [21]. The test and procedures are complied with BS 1881: Part 106:1983 (Methods for determination of air content in fresh concrete) [19].

2.4. Penetration resistance test

This test is used to determine the setting time of concrete by measuring the penetration resistance of concrete sieved from a sample of the fresh concrete. It includes a hand-held penetrator which is spring-loaded and graduated instrument with various sizes and shape of penetration needles. From a plot of penetration resistance versus elapsed time, the initial and final setting times are determined. The initial setting time is the elapsed time required for the mortar sieved from the concrete to reach a penetration resistance of 3,5 N/mm^2 (500 psi) after the initial contact of cement and water. The finial setting time is the elapsed time required for the mortar sieved from the concrete to reach penetration resistance of 27,6 N/mm^2 (4000 psi) after the contact of cement and water.

The test and procedures are complied with ASTM C403-92 (Time of setting of concrete mixtures by penetration resistance) [20].

3. Results

Tests were carried out and results are reported. Tables 3 and 4 show the properties of different fresh concrete mixes, such as, slump, Vebe times, air content, and initial and final setting time.

4. Discussion

4.1. Slump of FRC

Fig 1 shows the slump and the Vebe time of all fresh mixes. All mixes were tested under the same conditions. The slump of OPC mix (Mix C) was 50 mm while the slump of Mix CP was 20 mm. The fresh polypropylene fibre reinforced concrete had lower slump than the control (without fibres).

With the addition about 0,2 % (volume fraction) of polypropylene fibres, the slump test was lowered by approximately by 40 %. Similar observations were made by other researchers [7–9, 22]. The workability of concrete is largely reduced by the addition of small amount of polypropylene fibres in concrete.

It was observed that the fibres increased the cohesiveness of the fresh concrete. In fact, polypropylene fibres have a thixotropic effect on the fresh concrete mix. This contains advantages and disadvantages. Practically, the thixotropic effect is shown as a resistance to slip when casting on gradients or slopes and as reduction in bleeding and settlement, and as control cracking of plastic shrinkage [23]. On the contrary, the thixotropic effect will affect the slump test to show a lower workability rather than the actual workability of the concrete mix. It is because of the larger creation of frictional resistance between the polypropylene fibres and the fresh plain concrete. As a result, Mix CP had lower slump than Mix C.

Table 3. Fresh properties of different mixes*

Mix ID	W/C ratio	Unit mass (kg/m^3)	Slump (mm)	Vebe time (seconds)	Air content (%)
C	0,5	2365,4	50	5	0,6
CP	0,5	2361,5	20	10	0,8
CPF	0,5	2360,5	25	7	0,9
CPS	0,5	2362,6	20	15	0,9

* All tests were measured under 21 °C and 65 % relative humidity.

Table 4. Experimental initial and final setting time of different mixes

Mix ID	Experimental initial setting time (minutes)	Experimental final setting time (minutes)
C	345	446
CP	320	431
CPF	356	482
CPS	264	357

* All tests were measured under 21 °C and 65 % relative humidity.

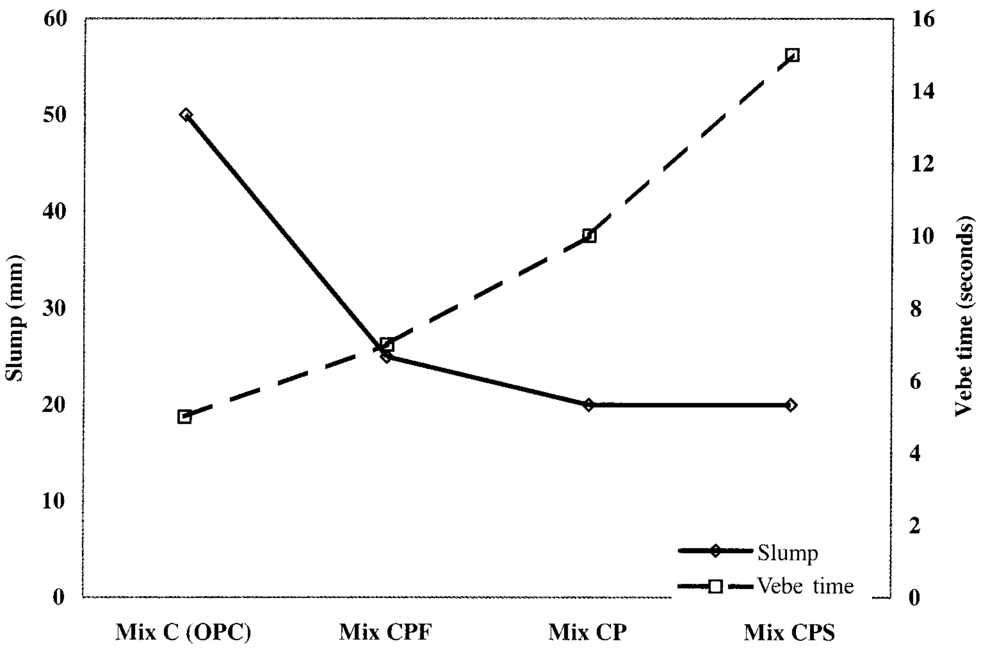

Fig 1. Variation of slump and Vebe time

4.2. Slump of fresh FRC under the influence of PFA

Referring to Fig 1, the slump of Mix CPF was 25 mm while the slump of Mix CP was 20 mm. With 10 % partial replacement of cement by fly ash on FRC, the slump was increased by 25 %. Higher workability of FRC was obtained due to the presence of PFA.

Generally, the presence of PFA has the ability to decrease the water demand of concrete without affecting this workability. For a constant amount of water, the partial replacement of cement by PFA can improve the workability of ordinary Portland cement concrete. This is attributed to the small size and the typically spherical shape of PFA [11]. The partial replacement of cement by PFA for an equal weight gave rise to a volume increase due to the lower specific gravity of PFA compared with that of cement. Thus more effective coatings of fibre and lubrication of the aggregates and fibres were achieved. As a result, PFA reduced the interparticle friction and enhanced the compaction characteristics of fibre mixes concrete. Therefore Mix CPF had higher slump than Mix CP. The rheological properties of the FRC under the presence of PFA can be improved.

4.3. Slump of fresh FRC under the influence of SF

As can be seen in Fig 1, the slump of Mix CPS was 20 mm while the slump of Mix CP was also 20 mm. The partial replacement of cement by SF had no effect on the workability of ordinary concrete (Mix C). According to ACI Committee 226 [11], the use of SF adversely affected the workability properties of the mixtures. It is because the presence of SF produces an increase in the content of fines, and hence an increase in water demand is anticipated. With partial replacement of cement by SF, the workability of ordinary Portland cement concrete was decreased. On the other hand, the SF mixture was found to be cohesive.

During testing, the Mix CPS was found to be much more difficult to handle than Mix CP. A more cohesive feeling was encountered. This finding was also quantified by the measured Vebe time values in which the Vebe time for the Mix CPS was 15 seconds and that for the Mix CP was 10 seconds (from Fig 1). According to Spadea *et al* [24], when fibres and silica fume are both incorporated, serious problems of lack of flow properties could arise particularly without adding a superplasticiser.

Due to the combination of SF and polypropylene fibre, the slump value should be decreased largely. From Fig 1, the slump values of the polypropylene fibre mixed concrete (CP, CPS and CPF) were very close. This shows that the slump test is not appropriate for fibre concrete.

McWhannell [23] stated that the slump values did not always provide an accurate indication of the flow properties of fresh fibre concrete mixes. Moreover, it was not a good method to measure the workability under the presence of thixotropic effect. In order to obtain a more accurate measurement, a dynamic test is used to overcome the thixotropic effect. As a result, the Vebe test is a better method to measure the workability of FRC than slump test [25, 26].

4.4. Vebe Time test of FRC

The relationship between the slump and the Vebe time test is also shown in Fig 1. For the properties of concrete, the higher the slump, the lower the Vebe time is obtained. However, the slump is very insensitive at lower workability while the Vebe time is not sensitive at higher workability. Therefore, Vebe time test is used to measure the workability of FRC.

From Fig 1, Mix C had the lowest Vebe time of 5 seconds but the highest slump value of 50 mm was achieved. Mix CP had Vebe time of 10 seconds which is higher than Mix C by about 50 %. This implies that there was less workability in Mix CP than Mix C. The addition of the fibre increased the cohesiveness of concrete. The energy required for vibration of FRC was more than for plain concrete. The required energy was proportional to the fibre in the concrete. This result was in line with ACI Committee 544 [27].

Although the Vebe time test would lower the thixotropic effect to get the accurate level of workability, it cannot reduce the whole effect. Polypropylene fibres still physically affected the fresh concrete in small amount by the roughened surface area to create friction.

However, the stiffening effect of the fibres may largely disappear under vibration. Therefore, slump test based on static conditions in workability test can be misleading. The concrete is in fact workable when vibrated. As a result, the workability test involved the dynamic effects which can be used to assess the workability of fresh FRC [1]. From Fig 1, ACI Committee 544 [27] stated that the inverted cone method is another appropriate method to measure the workability of fibre concrete.

4.5. Vebe time of FRC under the influence of PFA

Referring to Fig 1, Mix CPF had Vebe time 7 seconds while Mix CP had 10 seconds. With 10 % PFA on FRC, the Vebe time was decreased by 30 %. Higher workability was obtained on Mix CPF under the influence of PFA. The lubrication effects of PFA improved the dispersability of fibres and the workability of fresh mixes. The explanation was similar to the slump test due to the spherical shape of fly ash. The interparticle friction between the fibres and matrix could be reduced. The improvements in the workability of fresh mixes were obvious by using vibration test under the presence of PFA. Therefore small amount of energy was required to level the concrete. The improvements in the workability of fresh mix and in fibre dispersability might enhance the properties of the composite material in hardened state.

4.6. Vebe time of FRC under the influence of SF

In the same plot, Mix CPS had Vebe time 15 seconds it was relatively higher than the Vebe time of Mix CP (10 seconds). With 10 % SF on FRC, the Vebe time was increased by 50 %. SF decreased the workability of FRC by a large amount. The fineness and high pozzolanic reactivity of silica fume make it highly effective in enhancing the structural density and adhesion capacity on the bulk of the cement paste, especially within the interface zones between the paste and fibres. Due to its properties, it became cohesive that decreased the workability. Therefore more energy was required to vibrate the concrete, the Vebe time of Mix CPS was longer than Mix CP.

4.7. Comparison of slump and Vebe time

Slump test is very simple, therefore it is suitable for using on site. Moreover, less technique on the operation will be required. But as for the Vebe time test, the apparatus is more expensive and it is not suitable on site due to its size and weight. The Vebe time test is an appropriate method in the laboratory to measure the workability. Also more technical knowledge shall be required.

In this study, Vebe time test is a good method to show the influence of polypropylene fibre on OPC concrete, and PFA and SF on FRC. Table 5 compares the sensitivity of slump test and Vebe time test due to the influence of above factors.

Obviously, the Vebe time test shows more clearly the degree of workability under the influence of polypropylene fibres and the influence of PFA and SF on FRC because of thixotopic effect of fibres reduced by vibration. Slump test performed in the absence of vibration in these abnormally cohesive mixtures is not a good measure of workability and associated handleability and placeability of FRC. As a result, Vebe time is a good indicator of the degree of workability in fibre concrete and a more effective method for distinguishing the influence of PFA and SF on the fibre concrete workability.

Table 5. Sensitivity of slump and Vebe time test under the influence of the same factors

Factors	Percentage difference of workability under the factors	
(Mix a: Mix b)	Slump test	Vebe time test
Polypropylene fibres (Mix CP : Mix C)	40 %	50 %
Fly ash (PFA) (Mix CPF : Mix CP)	25 %	30 %
Silica fume (SF) (Mix CPS : Mix CP)	0 %	50 %

$$\text{Percentage difference} = \left| \frac{\text{Mix a} - \text{Mix b}}{\text{Mix b}} \right| \times 100\ \%$$

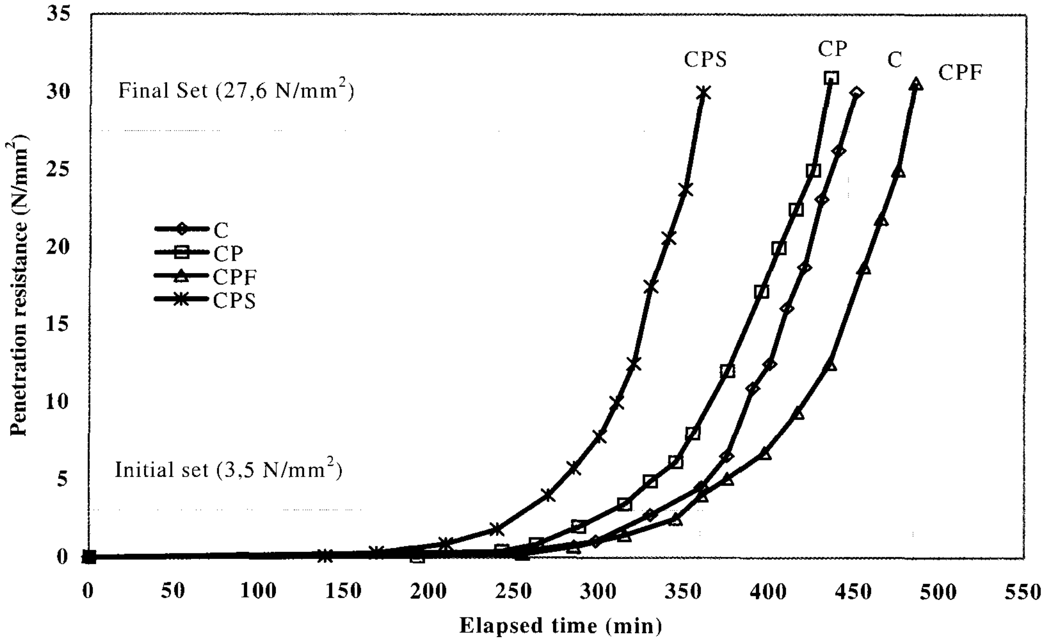

Fig 2. Variation of penetration resistance with time elapsed (1)

4.8. Air content

It was experimentally found that the air content of fresh concrete (0,6 %) can be increased by the presence of polypropylene fibres (0,8 %). Partial replacement of cement by either PFA or SF encourages further increase in air content (0,9 %).

4.9. Setting time of FRC

In order to investigate the influence of polypropylene fibres on concrete and the influence of fly ash and silica fume on fibre reinforced concrete, not only the chemical aspects of hydration reactions of Portland cement compounds should be discussed, but also it is desirable to pay attention to the physical aspect, such as setting times. Fig 2 shows the variation of resistance penetration of all mixes with elapsed time.

From Fig 2, the initial setting times that correspond to a penetration resistance of 3,5 N/mm^2 for Mix C and CP were 345 and 320 minutes respectively. While the final setting times corresponding to a penetration resistance 27,6 N/mm^2 for Mix C and CP were 446 and 431 minutes respectively.

Generally, the setting times of Mix C and Mix CP are very close. With the presence of 0,2 % polypropylene fibres in the fresh concrete, the setting time was slightly smaller than the concrete without fibres. This implies that the rate of stiffening of the FRC is faster than the control (without fibres). According to Ritchie *et al* [28], the rate of stiffening of fresh FRC was increased because fresh fibres mix was much more cohesive and the internal resistance of fresh FRC was increased.

During the test, Mix CP had a reduced bleeding than Mix C in fresh state because the surface of polypropylene fibre increased its affinity with the cement matrix (polypropylene bonding).

While from Balaguru *et al* [7], the initial and final setting times measured in terms of penetration resistance, were essentially the same for plain and fibre reinforced concrete. Actually, in their research, steel fibres were used. In the present study, the difference was about 3 % and 7 % smaller on initial and final setting times respectively with the addition of polypropylene fibres compared with the plain concrete.

4.10. Setting time of FRC under the influence of PFA

Referring to Fig 2, PFA had a retarding effect on the setting time of the polypropylene fibre concrete mix. Mix CP without PFA reached the initial set and final set at 320 and 431 minutes respectively. Mix CPF reached the initial and final set at 356 and 482 minutes respectively. In other words, there is an increase of about 11 % of initial setting times and about 12 % of final setting times in the presence of PFA. This would be attributed to the slow pozzolanic reactions that occurred between PFA and CaO in the cement. Also, according to ACI Committee 226 [12], fly ash can delay the setting times of concrete.

During the setting time test, the amount of water bleeding for the Mix C was observed. It was noted that the Mix CPF showed a reduced bleeding and segregation relative to the Mix C and Mix CP.

4.11. Setting time of FRC under the influence of SF

From Fig 2, Mix CPS reached the initial and final set at 264 and 357 minutes which were less than the initial and final set of Mix CP at 320 and 431 minutes respectively. SF in FRC had an accelerating effect on the setting of polypropylene fibre concrete mix: there is a decrease of about 18 % of initial setting times and about 17 % of final setting times in its presence. Due to its high pozzolanic effect, it contributed to the hydration reaction between ordinary Portland cement and water.

During the setting time test, it was noted that Mix CPS showed a more reduced bleeding and segregation relative to the Mix C, Mix CP and even Mix CPF.

4.12. Empirical equation related to the initial and final setting times

Apart from the plot of penetration resistance versus elapsed time values, the setting times can be determined. The setting time can also be determined by a log-log plot of the penetration resistance versus elapsed time values. The plot on logarithmic scale shows that there is approximately a linear relationship between the penetration resistance and elapsed time on a log-scale and it is shown in Fig 3. The equations for each mix obtained by regression analysis are shown in Table 6.

From the above table, the calculated setting times are very close to the experimental setting times. That means the equations can be used to estimate the initial setting time and the final setting time for each mix.

According to American Standards [20], they both prescribe the final setting time as a maximum of 10 hours for Portland cements. In this study, the maximum final setting was 481,6 min of Mix CPF which was smaller than 600 min (10 hours).

From Neville *et al* [21], the initial setting time and final setting times are approximately related (Eq 1):

$$F_{st} = 90 + 1,2\ I_{st}, \qquad (1)$$

where F_{st} and I_{st} represent the final setting time (min) and the inittal setting time (min.) respectively.

In this study, the relationships between the calculated initial and final setting times are given below (Eq 2).

$$F_{st} = 74 + 1,1\ I_{st}. \qquad (2)$$

Fig 4 shows the relation between the initial setting time and final setting time in both cases.

In fact, there are some differences between the equations of Neville *et al* [21] and the present study. The reasons of the difference are given below.

Table 6. Equations to determine the initial and final setting times

Mix	Equation*	Correlation coefficient (r)	Calculated value (min)		Experimental value (min)	
			Initial setting time	Final setting time	Initial setting time	Final setting time
C	$Log\ PR = -19{,}58 + 7{,}94\ Log\ t$	0,988	342	444	345	446
CP	$Log\ PR = -18{,}69 + 7{,}68\ Log\ t$	0,996	319	418	320	431
CPF	$Log\ PR = -18{,}03 + 7{,}26\ Log\ t$	0,998	362	481	356	482
CPS	$Log\ PR = -14{,}21 + 6{,}11\ Log\ t$	0,998	260	364	264	357

* ***PR*** – Penetration resistance (N/mm^2); *t* – time (min)

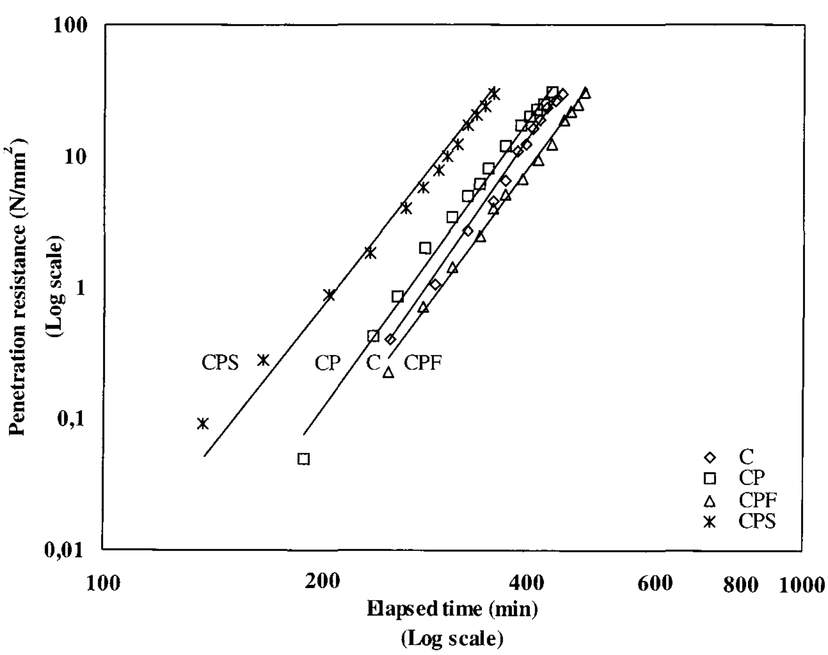

Fig 3. Variation of penetration resistance with time elapsed (2)

1. Since temperature and humidity affect the setting times seriously, the different environmental conditions affect the values. Therefore, the equations are different.
2. Also, different types of cement were used. Then different chemical composition would change the setting time.
3. The present of polypropylene fibre increased the cohesiveness and the internal resistance of the fresh concrete mix.
4. Basically, the different components inside the concrete will change the setting times. Particularly, the components which can change the rate of hydration of C_3A and C_3S, then the setting times will be affected. In this study, silica fume is added, so the setting time will be faster and the equation will have smaller y-intercept values.

5. Conclusions

In this study, the effects of polypropylene fibres at a volume fraction of 0,2 % on the workability were investigated. And the effects of fly ash (PFA) and silica fume (SF) on the properties of polypropylene fibre reinforced concrete (FRC) in the fresh state were investigated experimentally under the same conditions. According to the experimental investigation, the following conclusions were made:

5.1. Effect of polypropylene fibres

- addition of 0,2 % polypropylene fibres to concrete greatly reduced the workability due to the thixotropic effect of fibres. Lower slump and higher Vebe time were obtained in FRC compared with plain concrete.
- The Vebe time test is a more appropriate method than the slump test to measure the low workability of FRC and the workability of FRC with pozzolan.
- The setting times were slightly reduced by the addition of polypropylene fibres compared with plain concrete. The initial and finial setting times were reduced by about 3 % and 7 % respectively under the physical effect of fibres.

5.2. Effect of fly ash on FRC

- 10 % substitution of cement with PFA in the fibre concrete mixes generally had positive effects on the workability of fresh mix as represented by the Vebe time test. The slump test is not an appropriate method to indicate the degree of workability of the fibre concrete.
- The presence of PFA in the fibre concrete generally slowed down the rates of initial and final setting times. The setting times were increased by about 12 % than the ordinary fibre concrete.

5.3. Effect of silica fume on FRC

- The substitution of 10 % of SF decreased the workability of fresh fibre mix as represented by Vebe time test. Due to its fineness, high pozzolan reaction and high silica content, the combination of it and fibres adversely affected the workability.
- The initial and final setting times were decreased by about 18 % under the presence of SF on FRC. The silica fume fibre concrete was more cohesive and sticky than the ordinary fibre concrete. Besides, it indicates that the physical effects of fibres affect the setting times less than the chemical effect of the pozzolan (SF).

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