Parameter-Study on the Influence of Steel and Polyester Fibers in the Self-Compacting Concrete.

D.L. Shah and C.D. Modhere, Ph.D.

Applied Mechanics Department, SVNIT – Surat, India.

ABSTRACT

Self Compacting Concrete (SCC) is a relatively new type of concrete with high flowability and cohesiveness compared to conventional concrete. SCC offers several economical and technical benefits; the use of fibers extends its possibilities. Fibers are known to significantly affect the workability of concrete. Therefore, an investigation was performed to compare the properties of SCC with inclusion of steel and polyester fibers in order to answer the question to what extent the workability of SCC is influenced. The Slump flow, J-ring flow, V-funnel, L-box and U-Box tests were used to evaluate the material characteristics of the fresh concrete along with some hardened properties such as compressive strength, tensile strength and flexural strength of the same mixtures. Based on the results of the fresh properties of SCC with fibers, steel fibers produced more hinders in flow than polyester fibers, while in hardened state steel fibers gave better strength.

(Keywords: self compacting fiber reinforced concrete, fresh properties of SCC, steel fibers, polyester fibers, compressive strength)

INTRODUCTION

Self Compacting Concrete (SCC) is considered a concrete that can be placed and compacted under its own weight without any vibration effort, assuring complete filling of formworks even when access is hindered by narrow gaps between reinforcement bars. Concrete that must not be vibrated is a challenge to the building industry. In order to achieve such behavior, the fresh concrete must show both high fluidity and good cohesiveness at the same time.

The use of fibers might extend the possible fields of application of SCC. Fibers are added not to improve the mechanical properties itself, but also to control the cracking, prevent coalescence of cracks, and to change the behavior of the material by bridging the cracks. In other words, ductility is provided with fiber reinforced cementitious composites because fibers bridge the crack surfaces and delay the onset of the extension of localized crack [1–6]. Fibers are produced in a wide range of materials, in different shapes with divergent properties concerning their affinity to paste or water. They are known to affect the workability and the flow characteristics of concrete basically. The degree to which workability decreases does depend on the type and content of fibers used, on the matrix in which they are embedded and the properties of the constituents of the matrix.

Workability of SCC is determined both by the superplasticizer (SP) dosage and water/binder (w/b) value. Self compacting fiber reinforced concrete (SCFRC) is a remarkably sensitive not only to the w/b value and SP, but also to fiber types, fiber contents, aggregate properties as well as the SCC matrix, etc. For the workability of SCFRC, there are some essential factors of great importance: flowability, segregation resistance, passing ability through the steel bars and levelling ability.

The ratio of the length of fiber to its diameter is the aspect ratio (L/D). Higher aspect ratio and volume concentration (Vf) of fibers improve the performance of SCFRC in the hardened state but also adversely affect its workability[7].Thus, the product of these two parameters, which is termed as the “fiber factor”, has become a key index in comparing SCFRC mixtures. The size and amount of aggregate content also influences the workability of SCFRC [8-9].More fibers can be added as the fine aggregate content of the total aggregate is increased. Rossi and Harrouche [10] proposed a mix design method for fiber reinforced concrete that was based on the method of Baron–Lesage. They found that the optimum aggregate proportions were independent of the volume and properties of the paste. After varying the ratio of the sand to aggregate by trial and error, an optimum content of sand was found to achieve the best workability. This ratio depended on the type and amount of fibers. Next, an adjustment of the water, cement and superplasticizer has to be performed to attain the desired workability. Usually, the cement content has to be adjusted if a higher sand content was applied.

SCC reinforced with steel fibers enhances its application because the mechanical performance of concrete is improved. SCFRC is more ductile and tougher than conventional SCC and has demonstrated higher residual strengths(11).SCC reinforced with polyester fibers reduces micro cracks, crack propagations and increase shrinkage resistance but they are temperature sensitive and somewhat hydrophobic. Polyester fibers have been used at low contents to control plastic shrinkage cracking in concrete (12).

Because fibers are known to affect the workability of concrete, the question arises whether the fibers are detrimental to the workability of SCC. Therefore, an experimental study was performed on the effect of steel and polyester fibers at different contents on the workability of reference SCC mix. This paper presents the results of an ongoing experimental parameter study. The Slump flow, J-ring flow, V-funnel, L-box and U-box tests were performed to assess workability. Moreover, the compressive, splitting tensile and flexural strength tests were carried out to evaluate some hardened properties of the SCFRC.

EXPERIMENTAL DETAILS

Materials Used: Cement and fly ash were used as cementitious materials. Ordinary Portland cement (OPC) of 53 grade used conformed to IS 269:1989. The chemical properties of the cement are given in Table 1. The other important properties like specific gravity, setting time, consistency, etc., are summarized in Table 2. A class F fly ash (confirm to ASTM standard C 618-05, 2005) with a specific gravity 2.12 and loose bulk density 800 Kg/m^3 was used. Fly ash was obtained from thermal power plant (Ukai, India). The chemical characteristics of the fly ash are given in Table1. A polycarboxylate based Superplasticizer was used as a chemical admixture to enhance workability; the properties are given in Table 3.

Table1: Chemical Properties of Cement and Fly Ash.

Compounds	Cement (%)	Fly ash (%)
Si_2O_3	19.5	64.90
Al_2O_3	4.12	25.80
Fe_2O_3	6.06	04.14
MgO	1.53(6%max)	Nil
CaO	60.81	03.36
Na_2O	0.05	00.14

Table 2: Physical Characteristics of Cement.

Characteristics	Values
Loose bulk density	1470 Kg/m^3
Specific gravity	2650 Kg/m^3
Setting time: Initial setting time Final setting time	 29 min 580 min
Compressive strength : 7 days(MPa) 28 days(MPa)	 31.13 49.55
Consistency(w/c)	0.33
Passing through 90µ	5.2%

Table 3: Characteristics of Chemical Admixture.

Admixture type	Superplasticizer (polycarboxylate based)
Density(g/ml) at 25^0 c	1.09
Solid content	33
pH	8 $\pm$ 1

Locally available fine and coarse aggregate was used. The fine aggregate consisted of river sand with maximum size of 4.75 mm and coarse aggregate as crushed stone with size range of 0-10 mm .An important properties of coarse and fine aggregates are given in Table 4.

RC35/65BN steel fibers (Dramix) having a “trough” shape with hooks at both ends have a length of 35 mm, a diameter of 0.55 mm, an aspect ratio (ratio of length and diameter of the fiber) of 65 and a tensile strength of 1000-1100 MPa was used. The steel fibers were relatively stiff and glued into bundles.

The water-soluble glue dissolves in concrete during mixing, thus dispersing the fibers in the mixture. The content of steel fibers in SCSFRC mix was 40 kg/m^3.Locally available polyester fiber (Recron3s) of 12 mm long and 0.075 mm diameter having tensile strength of 400-600 MPa with a dosage of 1.5 kg/m^3 were used in SCPFRC (self compacting polyester fiber reinforced concrete).

Table 4: Properties of Coarse and Fine Aggregates.

Coarse Aggregate	Values
F.M.	7.2
Bulk density (kg/m^3)	
(a) Loose	1278
(b) Compacted	1530
Specific gravity	2.85
Fine Aggregate	**Values**
F.M.	3.04
Bulk density (kg/m^3)	
(a) Loose	1700
(b) Compacted	1949
600µ passing, Zone II, (IS 383-1970)	37.2%
Specific gravity	2.65

Reference SCC

The mixture proportions of an M30 reference concrete fixed after several trials. To achieve self compacting concrete, the content of the cementitious materials kept constant of 600 kg/m^3. The proportions of the aggregate were 40% coarse and 60% fine by the total weight of the aggregate. The volume ratio of coarse aggregates to concrete was 0.26. For fixing the proportion of water/binder (w/b) ratio and dosage of super plasticizer (SP), various trial mixes were conducted for 0.01 m^3 of SCC by varying dosage of water and Superplastcizer through slump flow test. Targeted minimum slump flow for the reference mix was 650 mm. The final mix composition of SCC is given in Table 5, (i.e. Cement: Fly ash: Coarse aggregate: Fine aggregate: Water = 0.181: 0.0776: 0.26: 0.39: 0.09); is considered as a reference SCC mix.

Table 5: Composition of Reference Mix.

Component	Quantity(kg/m^3)
Cement	420
Fly ash	180
Coarse aggregates (<10 mm)	600
Fine aggregates	900
Water	210
Superplasticizer	9

Mixing Procedure: The mixing process for all batches was follows; the coarse and fine aggregate were initially dry mixed for about 30s; this was followed by the addition of cement, fly ash and 1/3 of total mixing water; after 1.5 minutes of mixing, the rest of the mixing water together with the superplastcizer was added. All batches were mixed for a total mixing time of 4 minutes in a pan type mixer of 60 litre capacity. In case of a mix with fibers, the further mixing time at this stage was increased for 1 minute. Thus, non fibrous concrete mix was mixed for approximately 4 minutes while fibrous concrete mixtures were mixed for 5 minutes. Five types of workability tests were performed on fresh concrete mixtures, Slump flow, J-ring flow, V-funnel, L-box and U-box. The self compactability of the SSS/SCFRC was examined according to standards of Self Compacting Concrete Committee of EFNARC[15].The hardened properties of mixtures were prepared by direct pouring of concrete into the molds without compaction as seen in Figure 6.

Fresh Properties Tests: After the mixing was completed, all workability tests were conducted near the mixer machine waiting for 60s.The fresh properties results of SCC mixtures are given in Table 6.

Slump Flow Test: Filling ability and flowability of the SCC /SCFRC mixtures were tested using the slump flow test. The slump flow is the mean diameter of the horizontal spread of the concrete mass, after lifting the slump cone as seen in Figure 1 T_{50} time was also recorded during the slump flow test. T_{50} is the time required by the concrete mass to spread to 50 cm diameter, indicating the filling ability of the mix. Targeted minimum slump flow and T_{50} time for the reference mix was 650 mm and 3- 7 seconds.

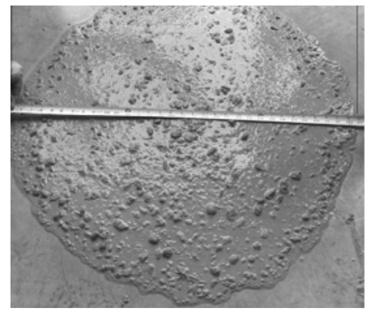
J-Ring Test: It is an extension of slump flow test and indicates the passing ability of concrete as seen in Figure 2. It can also be used to investigate the segregation resistance of SCC. A J-ring test is performed by lifting the slump cone and allowing SCC/SCFRC to flow radially outward through the J-ring. The flow of mix is obstructed by the bars, thereby creating a difference of level in the concrete (quantified as the J-ring value) that is inside the J-ring and the one that has passed through it. Targeted J-ring value for the reference mix was less than 10 mm.

Table 6: Fresh Properties Results of SCC Mixtures.

Mix	Properties Related to Self-Compactability					
	Slump flow (mm)	T50 (Sec)	J-ring Flow (mm)	V-funnel Time (sec)	L-box (H2/h1)	U-Box (H2-h1) mm
SCC	670	< 4	6	9	0.98	10
SCPFRC	630	< 6	15	14	0.85	35
SCSFRC	590	< 10	22	17	0.76	55

- *SCC: Self compacting concrete*
- *SCPFRC: Self compacting polyester fiber reinforced concrete*
- *SCSFRC: Self compacting steel fiber reinforced concrete*

(a)



(b)

Figure 1: Set-up for Slump Flow Test.

(a)

(b)

Figure 2: Set-up for J-Ring Flow Test.

V-Funnel Test: This test is used to assess the viscosity, flowability and segregation resistance of SCC, which indicates the period of a defined volume of SCC, needs to pass through a narrow opening. Flowability of SCC/SCFRC was evaluated using the V-funnel test by measuring the time (T in seconds) taken for the mixture to completely empty out through the V-funnel, which had a rectangular opening of 76 mm x 64 mm as seen in Figure 3. The targeted V-funnel time for the reference mix was less than 10 seconds.

L-Box Test: This test can assess the flowability, passing ability and leveling ability of concrete. SCC/SCFRC mixtures poured into the vertical shaft and fill it up top, and then the sliding shutter is opened and the mixture is allowed to fall and to flow under its own weight, passing through three steel bars of 16 mm diameter into the trough as seen in Figure 4. The overflow height H1 and H2 have to be measured at both the ends. Targeted value of blocking ratio (H2/H1) for the reference mix was 0.9-1.0.

Figure 3: Set-up for V-funnel Test.

U-box Test: This test is conducted to measure the passing ability and leveling ability of SCC. The equipment has the shape of English alphabet 'U' that is divided by a middle wall into two compartments as shown in Figure 5. An opening with a sliding gate is fitted between the two compartments with vertical reinforcements as obstructions. Concrete is filled in one compartment up to the top. After 30s, the sliding gate is lifted to allow the concrete to flow into the other compartment through reinforcement obstacles. After the concrete comes to the rest, the level difference between the top surfaces of concrete in the both compartments is measured. Height difference value less than 30 mm was targeted for the reference mix.

Hardened Properties Tests: In addition to fresh properties, some hardened properties of the SCC/SCFRC were also determined. These include the compressive strength, splitting tensile strength and flexural strength. After conducting the flow characteristics, the concrete mix was poured in the concrete cubes of 225 mm^2 cross section, cylinders measuring 150 mm in diameter and 300 mm in height, and beams 100 mm^2 cross section and 500 mm long were casted for each mix near the concrete mixer machine. After pouring the concrete into the molds, no compaction was given either through vibration or tamping. At least three specimens were tested for each of the hardened properties for 7 and 28 days. The specimens were demolded after 24 hours of casting and transferred to the water curing tank and were allowed to cure for 7 and 28 days. The specimens were tested under Universal testing machine of capacity 100 MT. Table 7 presents the test results of various hardened properties.

(a)

(b)

Figure 4: Set-up for L-box Test.

(a)

(b)

Figure 5: Set-up for U-box Test.

Table 7: Hardened Properties Results of SCC Mixtures.

Mix	Hardened properties					
	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	7 days	28 days	7 days	28 days	7 days	28 days
SCC	22.5	29.9	2.65	4.13	3.00	4.40
SCPFRC	24.0	32.0	2.92	4.83	3.30	5.30
SCSFRC	27.7	37.7	3.49	5.77	4.40	7.30

- *SCC: Self compacting concrete*
- *SCPFRC: Self compacting polyester fiber reinforced concrete*
- *SCSFRC: Self compacting steel fiber reinforced concrete*

RESULTS AND DISCUSSION

As can be seen from Table 6, slump flow test of reference SCC mix seemed to be more affected by the inclusion of steel fibers compared to polyester fibers, giving lesser slump flow value. Hooked end steel fibers of 80 kg/m^3 and with polyester fibers of 3 kg/m^3, produced strong negative influence on the workability were observed during the trial mixes of SCC with fibers. The observations indicated that the mixtures did not flow homogeneously. First; it was observed that the flow spread of mixture was not circular. This indicates that the flow had been counteracted in one or more directions. Furthermore, it was observed that the cluster of materials remained at the center of the flow spread after the removal of slump cone.

The results indicate from Table 6 that the SCC and SCPFRC mixtures satisfied the targeted T_{50} time criteria of 3 - 7 seconds. It has been observed that the workability of SCFRC can be assessed better with J-ring, V-funnel, L-box and U –box than with slump-flow tests alone. In case of SCSFRC, the J-ring value was higher because the fibers (RC35/65BN) bridged the J-ring bars, causing blocking that resulted in a poor passing ability, While in SCPFRC mix with 12 mm polyester fibers demonstrated better passing ability. In case of passing ability tests, a comparison indicates that the fiber length, the fiber factor and the stiffening of the mixture in time as affecting factors in mix.

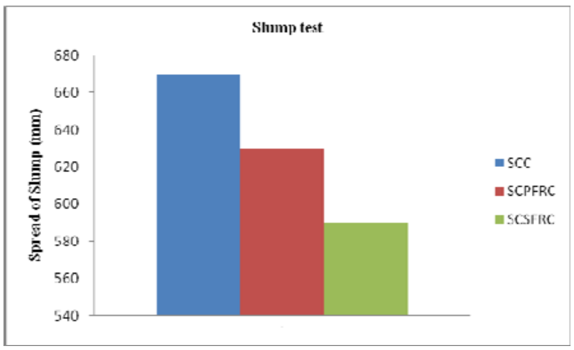
In conclusion, a larger bar spacing compared with normal SCC is required to avoid the risk of blocking of fiber-reinforced mixtures. Among the SCC and SCFRC mixtures, only SCC had a satisfactory J-ring value that is, within the targeted range of less than 10 mm. In case of V-funnel test, fibers partially blocked the opening of the V-funnel, thus increased the V-funnel time (T, seconds).In case of L-box and U-box tests, results indicate that the height difference between both the compartments was significantly affected by inclusion of steel fibers. For a better comparison of the fresh properties, the values from Table 6 are graphically presented in Figure 7. Important thing in evaluation of fresh properties is none of the mixtures showed bleeding.

The cylinders under compression failed mostly in the shear-type of failure mode for all mixtures. Fractured surfaces of SCSFRC mixtures showed the random orientation and uniform distribution of fibers throughout the specimen cross section. The failed surfaces of SCC mixtures specimens revealed uniform distribution of aggregate, confirming segregation resistance and stability of SCC produced. The surface finish of SCC and SCFRC specimens was sleek and superior. Observations of the fractured surface of SCSFRC revealed that the steel fibers were pulled out of the concrete and very rarely seen broken; is governed by the positive locking of the end hooks. Thus, it exhibited ductile failure mechanism compared to other mixtures.

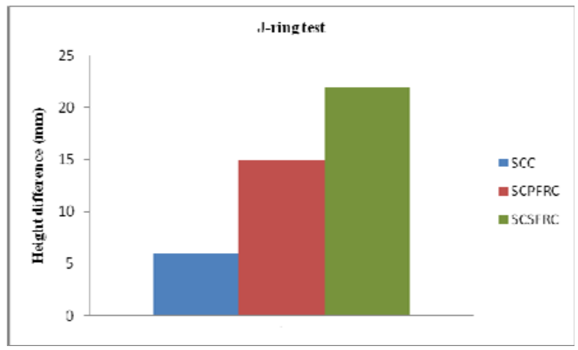
As observed from Figure 8, there was a steady increase in the strengths for all the mixtures as each mixture aged. The increase in compressive strength by the inclusion of fibers is marginal. The maximum increase in compressive strength was about 25% in SCSFRC. The increase in split tensile strength of SCSFRC is about 40% and 17% in SCPFRC with reference to SCC mix. Thus, the steel fibers clearly increased the split tensile strength of the self-compacting concrete. Past research has also reported an increase in split tensile strength of SCFRC [16].

(a) (b) (c)

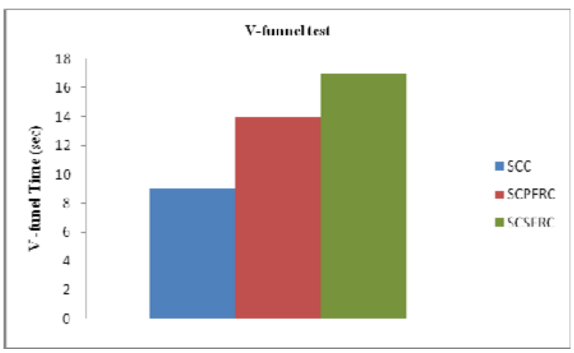
Figure 6: Hardened Properties of SCC.



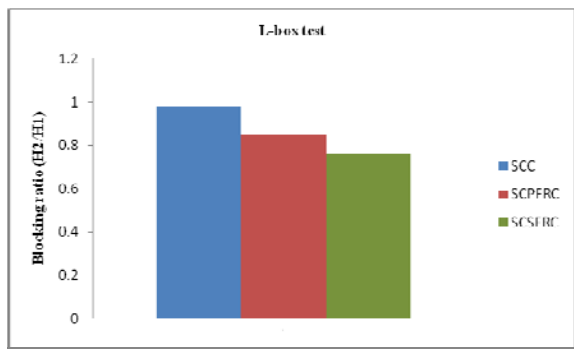
(a) Comparison of slump flow



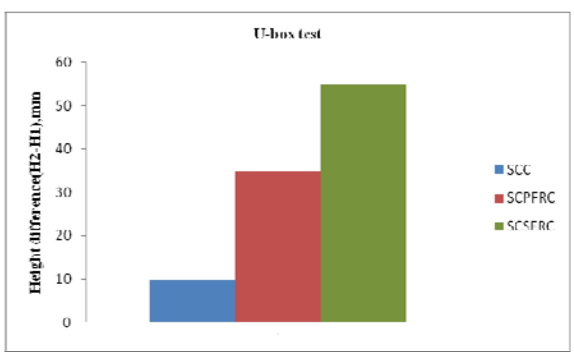
(b) Comparison of J- ring flow



(c) Comparison of V–funnel time (t)

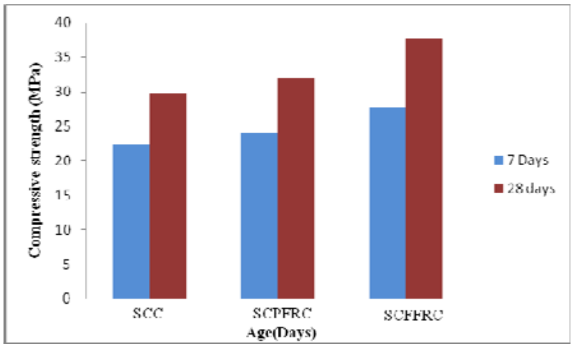


(d) Comparison of blocking ratio in L-Box

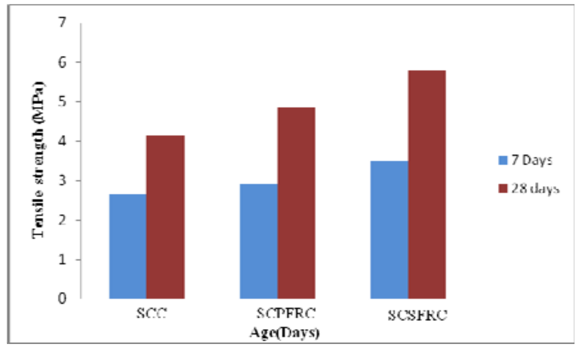


(e) Comparison of filling Ht. difference of U- box

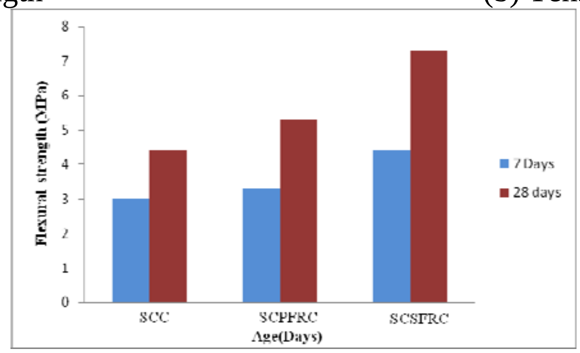
Figure 7: Comparisons of Fresh Properties of SCC Mixtures.



(a) Compressive strength



(b) Tensile strength



(C) Flexural Strength

Figure 8: Comparisons of Hardened Properties of SCC Mixtures.

As seen from Table 7, Steel fibers enhanced the flexural strength and thus increase the modulus of elasticity point out the additional advantage of using steel fibers in self-compacting concrete. For a better comparison of the hardened properties, the values from Table 7 are graphically presented in Figure 8.

CONCLUSION

The workability requirements for successful placement of SCC necessitate that the concrete exhibits excellent deformability and proper stability to flow under its own weight without segregation and blockage. It was observed that there were no problems in mixing of SCC with 0.5% hooked end steel fibers and 0.1% polyester fibers. The fibers distribution was uniform. However, SCSFRC mix exceeded the upper limits suggested by EFNARC[15]. All mixtures had a good flowability and possessed self compactability characteristics. In conclusion, the fiber length, geometry and dosage play an important role in SCC.

In hardened state, polyester fibers did not increased strengths much but reduce micro cracks, and crack propagations. SCC with hooked end steel fibers increased compressive strength 25 %, tensile strength 40% and flexural strength 65 % at 28 days. To use the advantages of SCFRC efficiently, all parameters affecting the properties of concrete in respect of the production and the durability of concrete structures should exactly be known. In this way SCFRC can be designed optimally. Finally, it was found that a considerable amount of fibers allowed in self-compacting concrete.

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ABOUT THE AUTHORS

D.L. Shah, is a Research Scholar and **Dr. C.D. Modhera**, is a Professor in the Applied Mechanics Department, SVNIT-Surat, India. Their research interests include methods for steel reinforcement and other topics in material sciences.

SUGGESTED CITATION

Oseji, J.O., O. Ujuanbi, and O. Merrious. 2009. "Determination of Ground Water Flow Direction in Ndokwa Land Area of Delta State Nigeria, using Combined Drilled Hole and Global Positioning System". *Pacific Journal of Science and Technology.* 10(2):178-186.

Pacific Journal of Science and Technology