International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 11 | Nov 2019 www.irjet.net p-ISSN: 2395-0072

USE OF NON DESTRUCTIVE TECHNIQUES TO ANALYZE FRESH AND HARDENED STATE PROPERTIES OF CONCRETE

K. Kishore[1], N. Ashok Kumar[2] and K. Ravi Theja[3]

[1]Student, M.Tech, Civil Department, SVTM, Madanapalle, A.P, India
[2]Assistant Professor, Civil Department, SVTM, Madanapalle, A.P, India
[3]Assistant Professor, Civil Department, SVTM, Madanapalle, A.P, India

---***---

Abstract: The present study deals with the non-destructive evaluation of concrete properties using electrical and ultrasonic methods. The objective of the study was to characterize the early age behavior of fresh concrete by the measurement of electrical properties and fiber distribution in hardened concrete by the application of a combination of ultrasonic method and AC impedance spectroscopy. Distribution and orientation of fibers in concrete has a profound effect on the hardened mechanical properties. AC impedance spectroscopy (AC-IS) is a useful tool to characterize bulk changes in the electrical properties of materials; thus, its application to fiber reinforced concrete is only natural. In this study, the impedance characteristics of fiber reinforced self-compacting concrete and normal concrete were measured using an impedance analyzer. Beam specimens were used to create a condition of one-directional flow of concrete during casting. The impedance response was measured in the direction of pouring concrete, in the direction of flow and in the orthogonal direction. The results from the response were presented in terms of the normalized matrix conductivity, the fractional function, the equivalent single fiber representation, and the dispersion factor.

The reduction of specimen width in the orthogonal direction led to the increase in alignment in the pouring direction. Similar trends were observed for self-compacting and normal fiber reinforced concrete. The ultrasonic method was not found to be sensitive enough at low fiber volume fractions (below 1%) to detect significant changes in the amplitude of signals in the direction of flow. The results of impedance spectroscopy were corroborated by the evidence from image analysis and manual counting, which indicated a higher orientation number in the direction of flow. Furthermore, the load carrying capacity and deformability of the composite was also found to be higher in the direction of flow.

Early age properties of cement mortars were studied by evaluating the resistance and capacitance response (represented in the results in the form of conductivity and dielectric constant, respectively) of the composite. A simple methodology for the detection of initial and final setting was proposed based on the trends in the variation of conductivity and dielectric constant with time, and the results from this method were within 15 min of the actual setting times determined using a penetrometer. The retardation of the reaction by the use of a retarder or fly ash, as well as the acceleration by the use of an accelerator, was clearly observed from the variation of the electrical properties. The two separate studies effectively brought out the potential of electrical measurement of properties of cement based materials.

Introduction:

Concrete is the most widely used construction material in world. A number of concrete structures built over the years are in various stages of deterioration. It is essential to inspect and analyse the quality of these structures to decide about their remaining service life, and also to arrive at suitable repair measures. Non-destructive evaluation (NDE) is thus necessary. However, apart from studying deterioration in concrete structures, NDE can also serve as a useful research tool (Punurai, (2006)). In fact, the use of NDE in research studies helps improve its application to the study of real structures. In this project, two innovative uses of NDE are demonstrated – one for studying the distribution of fibres in fibre reinforced self-compacting concrete, and the other for determining the early age characteristics of concrete, primarily setting and strength gain.

OBJECTIVE AND SCOPE:

The objective of the study is to characterise the setting behaviour of fresh concrete by electrical method and fibre distribution in hardened concrete by the application of a combination of ultrasonic and electrical methods.

The scope of the study is as follows:

a) Electrical response of the concrete (resistivity and capacitance) was measured in the fresh state to determine the early age properties. The influence of hydration and presence of mineral and chemical admixtures was also studied from the electrical properties.

b) The steel fibre orientation in concrete, subjected to different consolidation methods (self-compacting and vibrated), with different fibre volumes and different mould sizes, was studied using a combination of AC impedance spectroscopy (AC-IS) and ultrasonic methods. Image analysis of the tested concrete sections was used to check the validity of the results from the non-destructive tests.

METHODOLOGY

a. A review of the available literature on the use of ultrasonic pulse velocity and electrical methods in concrete studies was performed. Particular emphasis was given or studying early age properties of concrete and fibre distribution in concrete using these techniques.
b. Trials were conducted with LCR meter (which measures L – inductance, C – capacitance, and R – resistance) to develop suitable moulds for testing the hydration properties of concrete.
c. Mortar mixtures incorporating different admixtures were prepared in laboratory after necessary trials; these were tested for early age properties using the LCR meter.
d. Steel fibre reinforced self-compacting concrete mixtures were prepared with different dosages of fibres. At one fibre dosage, a normally vibrated concrete was also prepared.
e. Beam specimens prepared using the above mixtures were tested in the direction of flow and in orthogonal directions, using both ultrasonic pulse velocity and electrical impedance methods for evaluating the steel fibre distribution pattern.
f. A comparative analysis of the ultrasonic and electrical methods with respect to the study on fibre distribution was performed.

NEEDS FOR RESEARCH

The available literature indicates that a number of gaps in understanding exist with respect to the use of electrical and ultrasonic techniques for concrete studies. Further research is necessary in the following areas:

- Linking the change in electrical properties of concrete with the hydration processes taking place in the cement paste system.
- Evaluating the influence of chemical admixtures on the setting and hydration process using electrical methods.
- Evolving a simple procedure to define the setting time from electrical results.
- Determining the fibre orientation in beam specimens of fibre reinforced self-compacting concrete using AC impedance spectroscopy
- Applying ultrasonic pulse technique to study fibre orientation.
- Correlating ultrasonic and electrical impedance techniques for studying fibre orientation.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 11 | Nov 2019 www.irjet.net p-ISSN: 2395-0072

Chemical composition of cement, fly ash and silica fume

No.	Compound	Cement	Fly ash	Silica fume
1	SiO_2 (%)	19.50	61.60	82.16
2	Fe_2O_3 (%)	6.06	4.62	4.09
3	Al_2O_3 (%)	4.12	30.08	2.60
4	CaO (%)	60.81	1.75	2.34
5	MgO (%)	1.52 (6% max)	0.18	0.91
6	Na_2O (%)	0.05	0.76	2.58
7	K_2O (%)	0.28	0.36	4.20
8	SO_3 (%)	2.48 (2.5% max)	0.19	0.75
9	Total Loss on Ignition (%)	3.41 (4% max)	0.60	1.19
10	Ratio of % of lime to the % of silica, alumina and Iron oxide	0.93 (0.80-1.02)		
11	Ratio of % of alumina to that of Iron oxide	0.68 (0.66 min)		

Physical characteristics of cement

Characteristics	53 Grade Cement
Fineness: Specific Surface (m^2/kg)	316
Soundness: 1. Le chatelier (mm) 2. Autoclave (%)	2.0 0.2
Setting Time: 1. Initial Set (min) 2. Final Set (min)	99 184
Standard Consistency	(w/c) 0.33
Compressive Strength After a)3 days (MPa) b) 28 days (MPa)	a) 40.1 b) 74.3

Mix details and properties of concrete for fibre distribution studies

No.	Type of concrete	W/P	Cement content (Kg/m^3)	Fly ash content (Kg/m^3)	Fibre content (vol. %)	SP content (wt. %)	VMA (wt. %)	Slump Flow / Slump (mm)	T50 (sec)
1	FRSCC	0.33	400	180	1	2%	0.02	600	6
2	FRSCC	0.33	400	180	0.5	1.5%	0.02	630	5
3	FRSCC	0.33	400	180	0.25	1%	0.02	640	4
4	SCC	0.33	400	180	0	1%	0.02	700	3
5	FRC	0.33	400	180	0.25	0.5%		200	
6	NCC	0.33	400	180	0	0.25%		200	

Details of specimens cast for fibre distribution studies

No.	Type of concrete	Fibre content (vol. %)	Specimen Sizes		
			Beam	Beam	Cube
			150x150x750mm^3	100x150x750mm^3	150mm^3
1	FRSCC	1	✓		✓
2	FRSCC	0.5	✓		✓
3	FRSCC	0.25	✓	✓ (FRSCC D)	✓
4	SCC	0	✓		✓
5	FRC	0.25	✓		
6	NCC	0	✓		✓

Note:

FRSCC = Self compacting fibre reinforced concrete
SCC = Self compacting concrete
FRC = Fibre reinforced concrete

NCC = Normally compacted concrete
FRSCC D = Self compacting fibre reinforced concrete with beam size 100x 150 x750mm

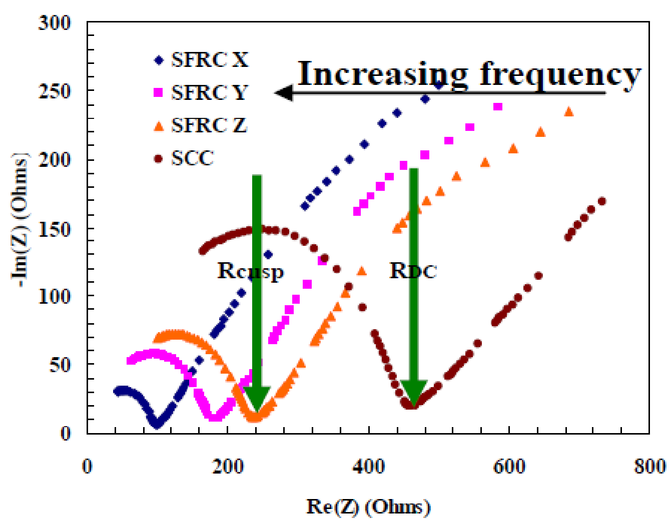
Mix details and properties of mortar for early age studies

W/P	Powder : Sand	Mix notation and mineral admixture dosage (% replacement of cement by mass)	Chemical admixture type and dosage (% by mass of cement)	Flow (mm)
0.4	1:2	Reference mix (without admixture)		145
		FA (30%) – with 30% Fly ash		130
		SF (10%) – 10% Silica fume		135
		ME (10%) - 10% Metakaolin		130
		ACC (2%)	Accelerator (2%)	140
		RE (1%)	Retarder (1%)	240

FIBRE DISTRIBUTION STUDIES

FIBRE DISTRIBUTION STUDIES BY AC-IMPEDANCE SPECTROSCOPY

In order to study the different fibre dispersion phenomena, the "intrinsic conductivity" approach was used. In composite systems with small amounts of conductive fibres (dilute regime), at low frequencies, the fibres behave as insulating materials and do not affect the measured composite resistance; thus, only the matrix resistance is measured, which is denoted as RDC. However, at high frequencies, when the fibres start conducting, the resistance of the composite decreases dramatically – this resistance is denoted as Rcusp. This phenomenon can be observed from Figure. which is a typical Nyquist plot obtained experimentally for self-compacting fibre reinforced concrete. From this figure it can be observed that with increase in the frequency, the composite resistance RDC (which is the resistance when fibres are inert) decreases to R_{cusp} (which is the resistance when fibres start conducting). The orientation of fibres in concrete can be assessed by normalizing the composite resistance with matrix resistance and by correlating it with fibre volume fraction. This approach is called intrinsic conductivity approach.



Typical Nyquist plot obtained experimentally for FRSCC with fibre volume fraction of 1% at section 2 in X, Y and Z direction

❖ FRSCC and SFRC represent same concrete

The following equation gives the governing equation for the intrinsic conductivity

$$\frac{\sigma}{\sigma_m} = \frac{R_{DC}}{R_{cusp}} = 1 + [\sigma]_\Delta \phi; \; \Delta = \frac{\sigma_f}{\sigma_m} \quad \text{---- (i)}$$

Where σ = composite conductivity, σ_m = matrix conductivity,
R_{DC} = Resistance at the low frequency cusp,
R_{cusp} = Resistance at the high frequency cusp,
$[\sigma]_\Delta$ = intrinsic conductivity,

Normalized matrix conductivity (N M C) at different sections in X, Y and Z direction

No.	Type of concrete	Fibre volume fraction (%)	Section 2			Section 3			Section 4		
			Direction			Direction			Direction		
			X	Y	Z	X	Y	Z	X	Y	Z
1	FRSCC	1	4.64	2.52	1.75	4.78	2.64	1.66	5.68	2.79	1.51
2	FRSCC	0.5	3.11	2.11	1.19	3.01	2.04	1.3	2.91	1.94	1.42
3	FRSCC	0.25	1.97	1.75	1.16	1.89	1.65	1.3	1.82	1.62	1.33
4	FRC	0.25	2.06	1.75	1.12	1.89	1.56	1.16	1.97	1.625	1.22
5	FRSCC D	0.25	2.06	1.42	1.19	2.05	1.34	1.25	2.00	1.28	1.35

φ = volume fraction of fibres, and
Δ = ratio of fibre conductivity (*σf*) to matrix conductivity (*σm*); ∞ for highly conducting particles.

Normalized matrix conductivity (N M C)
Fractional function representation

Fractional function method is one of the forms of representing the fibre orientation in the matrix. This representation was developed by Woo (2005); this method shows how much fibres are contributing to increased conductivity when compared to plain matrix in each direction. Therefore, it represents the relative amount of fibres orientated in a particular direction.

The Equation (i) can be rewritten as shown in Equation (ii)

$$\frac{\sigma}{\sigma_m} - 1 = \frac{R_{DC}}{R_{cusp}} - 1 = f = [\sigma]_\infty \phi = \text{F (geometry}, \phi) \quad \text{------(ii)}$$

Equation (ii) is known as the f-function
The effective f-function in each direction is calculated using Equation (iii)

$$\frac{\sigma_i}{\sigma_m} - 1 = \left(\frac{R_{DC}}{R_{cusp}}\right)_i - 1 = f = [\sigma]_{\infty,i} \phi; i = x, y, z \quad \text{----(iii)}$$

To get the number of fibres oriented in each direction, the effective *f*-function in each direction is normalized by the total sum of the three f-functions, which gives fractional function in each direction, as shown in Equations (iv) and (v):

$$\sum_{i=x,y,z} f = [\sigma]_{\infty,x}\phi + [\sigma]_{\infty,y}\phi + [\sigma]_{\infty,z}\phi .$$

$$\frac{f_i}{\sum_{i=x,y,z} f_i} = \frac{[\sigma]_{\infty,i}}{[\sigma]_{\infty,x} + [\sigma]_{\infty,y} + [\sigma]_{\infty,z}} ; i = x, y, z .$$

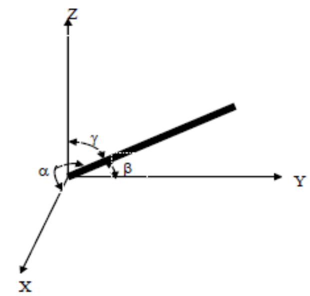
--(iv)& (v)

Fibre representation using fractional function at different sections in X, Y and Z direction

No.	Type of concrete	Fibre volume fraction (%)	Section 2			Section 3			Section 4		
			Direction			Direction			Direction		
			X	Y	Z	X	Y	Z	X	Y	Z
1	FRSCC	1	0.52	0.28	0.20	0.53	0.29	0.18	0.57	0.28	0.15
2	FRSCC	0.5	0.48	0.33	0.19	0.48	0.32	0.21	0.47	0.31	0.23
3	FRSCC	0.25	0.40	0.35	0.24	0.39	0.34	0.26	0.39	0.34	0.28
4	FRSCCD	0.25	0.44	0.29	0.25	0.44	0.28	0.26	0.43	0.27	0.28
5	FRC	0.25	0.42	0.36	0.23	0.40	0.34	0.25	0.4	0.34	0.25

Single equivalent fibre representation

Orientation of fibres can also be represented using a single equivalent fibre representation. This type of representation provides the angle that a single fibre would make to the three axes to reproduce the electrical response of the composite that is being measured (Woo (2005)). The fractional function in each direction gives the angle that the fibre makes with each axis, namely,α ,β ,γ which is angles that the single fibre makes to the X, Y and Z axes, respectively. The orientation of the single equivalent fibre is shown schematically in Figure.



Schematic showing the angles a single fibre makes to the three axes

The relationship between fractional *f*-functions and the measured angles is given as shown in Equation

Fibre representation using single equivalent representation at different sections in X, Y and Z direction

No.	Type of concrete	Fibre volume fraction (%)	Section 2			Section 3			Section 4		
			Angles			Angles			Angles		
			α	β	γ	α	β	γ	α	β	γ
1	FRSCC	1	44	58	64	43	57	64	41	58	67
2	FRSCC	0.5	46	54	64	46	55	63	47	56	61
3	FRSCC	0.25	50	53	60	51	54	59	51	54	58
4	FRSCCD	0.25	48	57	60	48	58	59	49	58	57
5	FRC	0.25	50	54	61	50	54	60	50	54	59

Dispersion factor (D F)

Another parameter which can be detected using

$$\frac{\sigma}{\sigma_m} = \frac{R_{DC}}{R_{cusp}} = 1 + [\sigma]_\Delta \phi;$$

$$\frac{\sigma}{\sigma_m} = \frac{R_{DC}}{R_{cusp}} = 1 + [\sigma]_\Delta \phi' + \sum [\sigma]_\Delta \phi_j;$$

$$\frac{f_x}{\sum_{i=x,y,z} f_i} = \cos^2 \alpha \quad \frac{f_y}{\sum_{i=x,y,z} f_i} = \cos^2 \beta \quad \frac{f_z}{\sum_{i=x,y,z} f_i} = \cos^2 \gamma$$

electrical impedance technique is fibre dispersion. There may be local aggregation of fibres due to clumping, which may affect the mechanical properties of the specimen. The dispersion of fibres and presence of clumping can be determined from impedance spectroscopy based on the dispersion factor approach developed by Woo et al. (2005). This approach compares the response of a composite system without clumping to a composite system with clumping. Equations shows response of the system without clumping and response of the system with clumping respectively.

By rearranging the Equations the dispersion factor can be arrived at as shown in Equation.

$$\mathrm{DF} = \left[\frac{\left(\frac{\sigma}{\sigma_m}\right)_{measured} - 1}{\left(\frac{\sigma}{\sigma_m}\right)_{theory} - 1} \right] = \frac{\phi'}{\phi} + \frac{\sum [\sigma]_{\Delta j} \phi_j}{[\sigma]_\Delta \phi}$$

Dispersion factor values for different concretes

No.	Type of concrete	Fibre volume fraction (%)	Dispersion factor
1	FRSCC	1	0.83
2	FRSCC	0.5	0.88
3	FRSCC	0.25	0.96
4	FRC	0.25	0.93
5	FRSCCD	0.25	0.87

ULTRASONIC METHOD

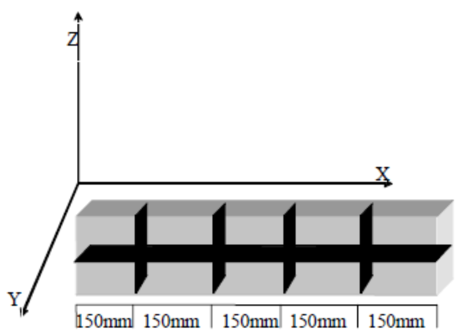
the typical amplitude versus frequency response of the ultrasonic signal (obtained from a Fast Fourier transform of the original ultrasonic time domain signal) for the SFRC with 1% fibre volume fraction (along with SCC without fibres). While there is no change in the frequency at the peak amplitude, the values of the peak amplitude are found to be highest in the X direction, indicating a possible preferential alignment in that direction. Even in the Y and Z directions, the amplitudes are higher than for the plain SCC, clearly showing the influence of fibres. The same trend seen in the figure for Section 3 was observed in the other sections also for 1% fibre volume fractions. A summary of the ultrasonic results is presented in Table 4.5. It can be clearly seen that when the fibre volume fraction is lower than 0.5 and 0.25%, the difference in amplitudes in the three directions becomes insignificant. Thus, it can be concluded that the ultrasonic method is unsuitable (or rather insensitive) for low fibre volume fractions.

Variation of ultrasonic amplitude at different sections in X, Y and Z direction

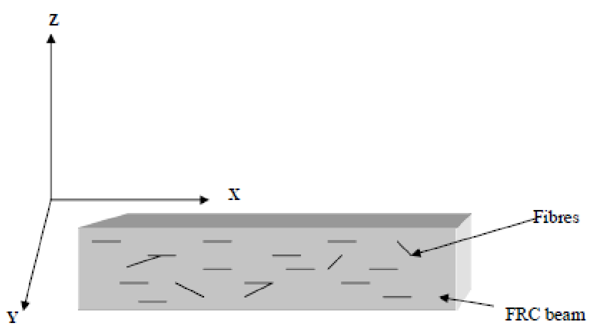
No	Type of concrete	Fibre volume fraction (%)	Amplitude(V)								
			Section-2			Section-3			Section-4		
			X	Y	Z	X	Y	Z	X	y	Z
1	FRSCC	1	46.7	29.1	26.0	46.3	31.0	28.7	51.6	31.1	28.0
2	FRSCC	0.5	30.9	26.2	28.6	33.3	32.0	30.0	30.0	28.0	27.0
3	FRSCC	0.25	18.0	20.0	17.0	16.0	17.0	17.0	17.0	16.0	18.0
4	FRC	0.25	19.0	18.0	19.0	18.0	20.0	17.0	17.0	19.0	18.0

IMAGE ANALYSIS AND MANUAL COUNTING

The cut sections from the cube specimens were observed visually and analyzed using image analysis and manual counting, in order to validate the results of the nondestructive measurements. Figure(a) shows a schematic diagram indicating the saw cut made along the beam for image analysis and (b) shows a schematic diagram indicating the orientation of fibres.



(a) Saw cuts made along the beam for image analysis and manual counting



(b) Schematic diagram of Fibre orientation

Fibre density values for different concretes

No.	Type of concrete	Fibre volume fraction (%)	Fibre density (fibres/cm^2) Section-2		Fibre density (fibres/cm^2) Section-3		Fibre density (fibres/cm^2) Section -4	
			ZY plane	XY plane	ZY plan	XY plane	ZY plane	XY plane
1	FRSCC	1	2.23	0.59	2.33	0.60	2.34	0.62
2	FRSCC	0.5	1.19	1.15	1.18	0.45	0.4	0.49
3	FRSCC	0.25	0.69	0.27	0.66	0.24	0.64	0.22
4	FRSCCD	0.25	0.66	0.26	0.71	0.29	0.70	0.28
5	FRC	0.25	0.71	0.29	0.67	0.26	0.65	0.25

Degree of orientation for different concretes

No.	Type of concrete	Fibre volume fraction (%)	Degree of orientation		
			Section- 2	Section- 3	Section- 4
1	FRSCC	1	0.69	0.68	0.68
2	FRSCC	0.5	0.56	0.59	0.6
3	FRSCC	0.25	0.55	0.51	0.6
4	FRSCCD	0.25	0.55	0.54	0.55
5	FRC	0.25	0.55	0.53	0.55

COMPRESSIVE STRENGTH

The compressive strengths at 28 days for the five concrete mixtures are presented in Table. No significant differences are seen between the different concretes (strength ranges from 50 to 54 MPa), indicating that there is negligible effect of fibres on the compressive strength (Shah and Balaguru, 1992).

Compressive strength values of different concretes

No.	Type of concrete	Fibre volume fraction (%)	Compressive strength (MPa) At 28 days of curing
1	FRSCC	1	54
2	FRSCC	0.5	53
3	FRSCC	0.25	50
4	FRC	0.25	51
5	SCC	-	50
6	NCC	-	51

FLEXURAL TESTS

Peak loads and CMOD for different concretes

No.	Type of concrete	Fibre volume fraction (%)	Maximum peak load(N)		CMOD (mm)	
			X	Z	X	Z
1	FRSCC	1	1730	1648	5.17	0.93
2	FRSCC	0.5	1549	1451	3.86	0.60
3	FRSCC	0.25	1373	1226	1.81	0.51
4	FRSCCD	0.25	1275	1324	1.73	0.30
5	FRC	0.25	1380	1315	1.74	0.30

EARLY AGE STUDIES ON CEMENT MORTARS

In this work the Electrical conductivity method has been used for studying the hydration characteristics. Aspects studied include:

a. The change in the capacitance and conductivity of the mixture during early hydration, especially at setting time.
b. The influence of frequency of applied voltage on both capacitance and conductance.

c. Effect of chemical and mineral admixtures on hydration characteristics, and development of compressive strength.

HYDRATION BEHAVIOUR AT EARLY AGES

Setting times using electrical and penetrometer test

No	Mix	Setting time using Electrical method		Setting time using Penetrometer method	
		Initial setting time (min)	Final setting time (min)	Initial setting time (min)	Final setting time (min)
1	Reference mix	235	370	240	350
2	SF (10%)	195	320	185	305
3	ME (10%)	195	290	180	280
4	FA (30%)	310	435	300	420
5	ACC (2%)	180	270	175	260
6	RE (1%)	NA	NA	720	900

Note – NA indicates that the setting points could not be determined

CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

FIBRE ORIENTATION STUDIES

- Studies on fibre distribution using AC-IS revealed that the composite resistance significantly varied in X (direction of flow), Y (direction perpendicular to the
- flow) and Z (pouring direction) directions. The orientation of fibres was observed to be preferentially in the X direction and in X-Y plane. The evidence for this statement is provided in the form of higher normalized matrix conductivity, greater value of f-function, and smaller angle (< 55o) made by the single equivalent fibre in the X direction.
- When the specimen dimension was reduced in the Y direction, the orientation of fibres in the Z direction increased compared to the Y direction. Fibre dispersion studies showed that with decrease in volume fraction of fibres, the dispersion factor increased. There was nearly 15% increase in dispersion factor for the concrete with 0.25% fibre volume fraction when compared to 1% fibre volume fraction. Fibre dispersion was not significantly different for high slump vibrated concrete and SCC (difference in dispersion factor was less than 5%).
- The ultrasonic method was found not to be as effective as AC-IS for fibre orientation studies, although at high volume fraction of fibres (1%), it showed good correlation with electrical impedance in the direction of flow, i.e. in X direction.
- Image analysis results showed that the orientation number was highest in the X direction, thus corroborating the results of the AC-IS studies regarding the preferential orientation of the fibres in the X direction. Furthermore, the higher loads and deformation capacity of specimens along the X direction adds further evidence to the preferential orientation.

FRESH STATE PROPERTIES

- A new methodology was proposed for the determination of setting time from the variation in electrical properties of the cement mortars monitored over the first 24 hours. The setting times determined using this methodology was within 15 min of the actual setting times found from the electrometer test.
- The effect of the frequency of the applied electric field on the conductivity was negligible at frequencies above 10 kHz. However, at the lower frequency of 1 kHz there was some effect of electrode polarization. The capacitance (dielectric constant) of the system, on the other hand, was greatly affected by the

frequency of the applied field; there was about three orders of magnitude decrease in the dielectric constant, when the frequency of the applied field was changed from 1 kHz to 100 kHz.

- The measurement of electrical properties was also able to characterize the alteration in cement paste hydration due to changes in composition (use of mineral and chemical admixtures). While the use of accelerator led to a rapid development of resistively of the mortar, the change in resistively at the early stages when retarded was used was negligible. In the case of mineral admixtures, the use of silica fume and met kaolin did not change the pattern of drop in conductivity, while the use of fly ash clearly showed a retardation of the drop in conductivity.
- At initial set time the dielectric constant value of the met kaolin mix was nearly 2 orders of magnitude higher than the silica fume, fly ash and reference mixes. This may be due to fact that the surface area of the hydration products may be more compared to the other mixes.
- The pattern of increase of resistively did not exactly match with the pattern of increase of compressive strength of the mortars, indicating that those two parameters did not exactly depend on the same set of factors. While the compressive strength is mainly dependent on the capillary porosity, the resistively is also dependent on the pore connectivity and degree of saturation.

SCOPE FOR FUTURE STUDIES

The use of non-destructive techniques for studying concrete properties is a vast field of study. The research study presented in this thesis attempted to evaluate fresh and hardened state properties using a combination of electrical and ultrasonic methods.
While sufficient evidence of the phenomena under observation was obtained from the results of the study, there are many other possible areas of research that need further exploration. Some of the prominent aspects are outlined below.

- Study of the effect of fibre aspect ratio and shape on fibre orientation.
- Study of fibre orientation in two-dimensional flow conditions (such as in slabs).
- Development of more sensitive signal processing techniques for studying the fibre orientation at lower fibre volume fraction using ultrasonic method.
- Correlating the development of electrical properties with the development of hydration products in the cement paste, and also with the evolution of heat upon hydration of the cement paste.
- Quantifying the effects of the pozzolanic reaction using measurements of electrical properties.
- Determination of capillary porosity and degree of saturation using electrical property measurements.

REFERENCES

1. **ASTM C 109/C 109M** (2005) Standard test method for compressive strength of hydraulic cement mortars. Annual book of ASTM Standards.
2. **ASTM C 403/C 403 M-05** (2005) Standard test method for time of setting of concrete mixtures by penetration resistance. Annual book of ASTM Standards.
3. **ASTM C 494/C 494 M-05a** (2005) Standard specification for chemical admixtures for concrete. Annual book of ASTM Standards.
4. **ASTM C 618 05** (2005) Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. Annual book of ASTM Standards.
5. **ASTM D 4643-87** (1987) Standard test method for determination of water (Moisture) content of soil by the microwave oven method. Annual book of ASTM Standards.
6. **Austin, S. A., P.J. Robins, and P.A. Jones** (2003) Spatial distribution of steel fibres in sprayed concrete and cast concrete. Magazine of Concrete Research, **55,** 225 -235.

7. **Balberg, I., C.H. Anderson, S. Alexander, and N. Wagner** (1984) Excluded volume and its relation to the onset percolation. Physics Review B, **30**, 3933- 3943.
8. **Calleja, J.** (1952) Effect of current frequency on measurement of electrical resistance of cement pastes. ACI Journal, **4**, 329-330.
9. **Calleja, J.** (1952) New techniques in the study of setting and hardening of hydraulic materials. Journal of the American Concrete Institute, **23**, 525-536.
10. **Campo M.A., L.Y. Woo, T.O. Mason , and E.J. Garbocz**i (2002) Frequency dependent electrical mixing law behavior in spherical particle composites. Journal of Electroceramics, **9**, 49-56.
11. **Celzard, A., E. McRae, C. Deleuze, M. Dufort, G. Furdin, and J.F. Mareche** (1996) Critical concentration of short conducting fibres in a nonconducting matrix. Physics Review B, **30**, 6209-6214.
12. **Chen P.W. and D.D.L. Chung** (1995) Improving the electrical conductivity of composites comprised of short conducting fibres in a non conducting matrix: The addition of a non-conducting particulate filler. Journal Electronic Material, **24**, 47-51.
13. **Christensen, B.J., T.O. Mason, and H.M. Jennings** (1992) Influence of silica fume on the early hydration of Portland cements using impedance spectroscopy. Journal of American Ceramic Society, **75**, 939-945.
14. **Dinakar, P.** Development of high performance self compacting concrete for aggressive environments, Ph.D. Thesis. Ocean engineering department, Indian institute of technology, Madras, India, 2005.
15. **Douglas, J.F. and E.J. Garboczi** Intrinsic viscosity and the polarizability of particles having wide range of shapes pp. 85-153. In **Prigogine** and **S. A. Rice** (eds.), Advances in chemical physics, **XCI,** John wiley and sons, Newyork, 1995.
16. **Ferraro, C.** C Advanced nondestructive monitoring and evaluation of damage in concrete materials, M.E. Thesis, University of florida, U.S.A. 2003.
17. **Fixman, M.** (1981) Variational method for classical polarizabilities. Journal of chemical Physics, **75**, 4040-4047.
18. **Gettu, R., D. R. Gardner, H. Saldivar, and B. E. Barragan** (2005) Study of the distribution and orientation of fibres in SFRC specimens. Materials and Structures, **38**, 31-37.
19. **Gettu, R., J. Izquierdo, P.C.C. Gomes, and A. Josa** (2002) Development of high strength self compacting concrete with fly ash: A four-step experimental methodology, Proceedings of 27th conference on our world in concrete and
structures, Singapore, 217-224.
20. **Gu, P., P. Xie, F. Yan, and J.J. Beaudoin** Micro structural characterization of cementitious materials: Conductivity and Impedance methods, In **Sidney mindness** and **J. Skalny** (eds.), Material science of concrete, 4, 1995.
21. **Hannnat, D.J.** Fibre Cements and Fibre Composites. Johnwiley and sons limited, Chichester, 1978.
22. **Hammond, E. and T. D. Robson** (1975) Comparison of electrical properties of various cements and concretes. The engineer, **199**, 78-80.
23. **Hixson, A.D., L.Y. Woo, M.A. Campo, and E.J. Garboczi** (2001) Intrinsic conductivity of short conductive fibres in composites by Impedance spectroscopy. Journal of Electroceramics, **7**, 189 -195.
24. **Hughs, B.P., A.K.O. Soliet, and R.W. Brierley** (1985) New technique for determining the electric resistivity of concrete. Magazine of Concrete Research, **37**, 243-248.
25. **IS - 12269** (1987) Indian Standard Specification for 53 Grade Ordinary Portland cement. Bureau of Indian Standards, New Delhi.
26. **IS - 383** (1970) Specification for coarse and fine aggregates from natural sources for concrete. Bureau of Indian Standards, New Delhi.
27. **Lappa, E.S. H**igh Strength Fibre Reinforced Concrete Static and fatigue behaviour in bending, Ph.D. Thesis, T U Delft university, Netherlands. 2007.
28. **Maxwell, J.C.** Electricity and magnetism, Oxford University, 1904.
29. **Maxwell, J.C.** A Treatise on Electricity and Magnetism**.** Dover publications, Newyork, 1954.

30. **Malhotra, V.M. and N.J. Carino** Handbook on Nondestructive Testing of Concrete. CRC Press, Boca Raton, 1991.
31. **Mason, T.O., A.D. Hixson, L.Y. Woo, and M.A. Campo** (2002) Impedance spectra of fibre reinforced cement–based composites. Cement and Concrete Composites, **24**, 457-465.
32. **McCarter, W.J. and P.N. Curran** (1984) The electrical response characteristics of setting cement paste. Magazine of Concrete Research, **30**, 42-49.