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Performance Studies on Strength, Thermal and Acoustic Properties on Concrete Panels with E-Waste (FR4) as Partial Replacement of Fine Aggregate

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Abstract

*Reliability of FR4, (a frame retardant composite material composed of woven fibre glass cloth with epoxy resin binder) kind of electronic waste along with optimum dosage of fly ash, as partial replacement of fine aggregate in concrete had been investigated. The key objective of this study is to determine the acoustic performance in terms of sound absorbance at low and high frequencies and thermal conductivity. Acoustic & thermal conductivity tests were conducted with different percentage replacement levels of fine aggregate (5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%) in concrete slab panels having cross section dimensions of 0.3m*0.3m and varying thickness say 0.05m, 0.10m, 0.15m, 0.25m. Analysis on the mechanical properties of hardened concrete are also presented. The research outcome revealed that FR4 exhibits sound performance in terms of mechanical properties when being replaced with 5% of fine aggregate and 10% of fly ash. Also this material has the potential to act as outer-cladding-element to absorb sound in structures like skyscrapers but it needs complete examination on site.*

Key-words: E-Waste (FR4), Thermal Conductivity, Compressive Strength, Acoustic Performance.

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1. Introduction

1.1. General

Electronic waste also called as E-waste, generated from man-made inventions in timely basis do not degrade possessing a serious threat to our country in terms of devastating the natural resources, environment and ecological cycle [1]. The rapid generation of E-waste in the last ten years is due to the boom in utilizing electrical and electronic equipments satisfying various needs. Developing India through digital mode is also a reason where it had set footprints on every manufacturing sector turning out to be a revenue [2]. According to Swachh India Report, India tops fifth among E-waste manufacturing countries like China, Germany, Japan, and United States of America with a whooping production of 1.8 million tons annually [3]. Also 95% of India's E-waste comes from non-organized sectors. The growth of E-waste market in India between 2014 & 2019 accounts for 26.22%. In future, especially in Delhi, about 1.5 lakh million tons of E-waste generation shall be expected in the year 2020 [4].

According to a recent survey, the generation of E-waste had been classified based on the mode of consumption, say 68% for house hold appliances, 27% for Information Technology, 2% for Imports and 3% for others [5]. As we know, this E-waste is hazardous as it contains toxic substances like arsenic, barium, copper, cobalt, lead, cadmium, mercury, polychlorinated biphenyls, dioxins and furans which are obtained from electronic devices like circuit boards, transformers, batteries, plastic casings, electronic cables insulated with PVC thus contaminating ecology, environment, ground water quality, landfilling and other natural resources which are being utilized by people on their day to day life [6]. Electronic and Electrical waste, famously known as e-waste items, don't disintegrate or spoil away. The blasting use of electronic and electrical gear has made another yet extremely hazardous stream of waste, called "electronic-waste", or essentially known as e-waste [7].

With the vicinity of fatal chemicals and dangerous substances in the electronic contraptions, transfer of e-waste is turning into an ecological and wellbeing bad dream [8]. E-waste is presently one of the quickest developing waste streams. Consistently, countless old PCs, cellular telephones, TV sets and radio gear are tossed, a large portion of which either wined up in landfills or unapproved reusing yards. With the numerous changes being made in stacking and ventilating equipment for homes, business and it is getting to be expanding imperative for draftsmen & specialists to have prepared access data on the warm protection properties of building materials [9]. Since the structural architects plan the warming & cooling plant on the premise of the later an hour of heat transmission through the expansion parts of the building, ideal proficiency sparing structure configuration requires analysis of relative warmth misfortune through the components of the structure [10].

The capacity of warmth exchanging limit of a solid divider module is to decide in this stage. The chunk modules are arranged utilizing with ordinary cement and E-waste included cement of distinctive. After the curing of 28 days, it is taken into consideration warm conductivity. Test to focus the warm protection property solid state module. There warm protection in the state module exchange low warm vitality, to the next side. The detail module is situated in the chamber and the warmth is connected on the one side and warm move in measure by the inhabitance achievement which is constrained in the state module [11].

1.2. Specific Heat

Ancient research had observed that the specific heat of concrete is affected by physiochemical process which occurs in the cement paste and aggregates greater than 600ºc. For conventional concrete, The specific heat remains constant up to 300°c thereby it elevates between 640°c and 800°c concluding that it has linear relationship with the temperature. When adding fly ash, the specific heat values are significantly increased resulting in reduced permeability than other types of concrete.

1.3. Thermal Conductivity

Thermal conductivity for any type of concrete decreases with the increase in temperature. The reason adheres with the background of the concrete say mix proportions, permeability and moisture content. The thermal conductivity of conventional concrete at 20°c is estimated to be 2.3(W/mk) whereas at 80°c, it is estimate to be 1.5 (W/mk). With respect to the concrete with fly ash based, the thermal conductivity is of 2.9 (W/mk) at 20°c and 1.3(W/mk) at 800°c.

1.4. Thermal Insulation

The thermal insulation varies inversely with density, light weight concrete has better thermal insulation properties then the normal conductivity for conventional Concrete. The thermal conductivity for conventional concrete is 20.8 w/m oC. Lightweight Concrete is generally lesser than the conventional concrete. The power supply for the heat application a micro processer board is used which is the board function of (Programmed). The heat energy is applied at the one side and it is measured by the sensors. While on the other side, the thermal observed (overall heat transfer coefficient) measured by the sensor using the steady state measurement technology, the thermal transfer is calculated. Thermal Conductivity for FR-4 is 0.29w/m oK to 1.059w/m oK. This also decreases with the increase in temperature. Low thermal diffusivity levels are expected to satisfy the behaviour of thermal insulation leading to drop in temperature during extreme weather conditions. It can be evaluated in terms of ratio of thermal conductivity to volumetric heat capacity.

1.5. Ultrasonic Properties

In this study, ultrasonic pulse velocity test (UPVT) is used. An ultrasonic pulse velocity test is an in-situ, non-destructive test to check the quality of concrete and natural rocks. In this test, the strength and quality of concrete or rock is assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure or natural rock formation. This test is conducted by passing a pulse of ultrasonic wave through concrete to be tested and measuring the time taken by pulse to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

1.6. Research Significance

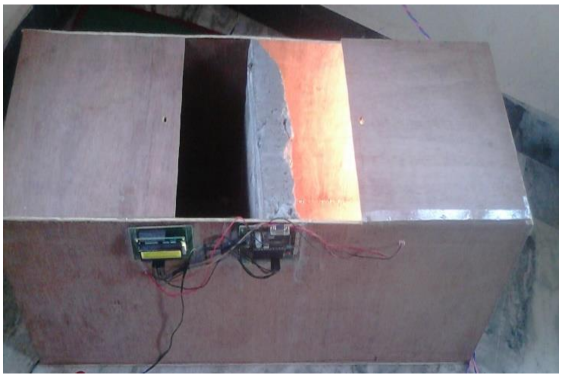
In accordance with ACI committee 211-1991, mix proportions for M20 grade of concrete are considered and shown in Table 5, Cube specimens -(0.15m*0.15m*0.15m), Cylindrical specimens – (0.15m*0.30m) are chosen for evaluating the mechanical parameters. Slab panels of 0.3m*0.26m in various thickness say 0.05m, 0.07m, 0.10m, 0.12m are chosen for evaluating thermal insulation. Sound absorption and insulation in low and high frequencies are assessed and compared with the conventional ones.

2. Methodology

2.1. Thermal Insulation

The concrete state module are casted for the sizes of 300mm X 260mm with the variation in the thickness 2'', 3'', 4''and 5''. The thickness variation of the state module represents the density of the concrete. After the curing, the state module is being kept in the middle of the closed chamber. The occupancy sensors are fixed in the sides of the state module to measure thermal energy liberation. An incandescent lamp is an extremely inefficient light source. A 100 watt bulb is 2.1% efficient. In other words, it produces about 2 watts of light and 98 watts of heat make ESU 200 incandescent 'Bright light'. The heat mass pass through the medium (Slab of conventional concrete and e-waste concrete with the size of 0.3m X 0.3m area) with various thickness Fig. 1 (a) and (b) shows the experimental setup and display unit. The calculation parts are carried out by the following equation.

Fig. 1- (a) Setup; (b) Display Unit



2.2. Ultrasonic Test

The concrete state module are casted for the sizes of 300mm X 260mm with the variation in the thickness 2", 3", 4" and 5". The thickness variation of the state module represents the density of the concrete. The Ultrasonic testing equipment includes a pulse generation circuit, consisting of electronic circuit for generating pulses and a transducer for transforming electronic pulse into mechanical pulse having an oscillation frequency in range of 40 kHz to 50 kHz, and a pulse reception circuit that receives the signal. The transducer, clock, oscillation circuit, and power source are assembled for use. After calibration to a standard sample of material with known properties, the transducers are placed on opposite sides of the material. Fig.2 shows the UPVT tested specimen as required for the study.

Fig. 2 - UPVT Tested Specimen

3. Materials Details

3.1. Selection of Materials

3.1.1. Cement

Ordinary Portland cement of grade 43 is considered for fabricating the proposed concrete structure. The physical properties are listed in Table 1.

3.1.2. Fine Aggregate

River sand passing through 4.75mm are chosen. The properties are listed in Table 2.

3.1.3. Coarse Aggregate

Crushed Hard Blue granite metals procured from local quarry are chosen. The properties are listed in Table 3.

3.1.4. E-WASTE (FR4)

Flame retardant composite material with the availability of oxides of calcium, aluminium, sodium, potassium, magnesium, iron and titanium with better strength to mass ratio have been taken into consideration for replacement of fine aggregate at different levels. The properties are listed in Table 4.

Table 1 – Physical Properties of Cement

S. No	Description	Results
1	Compressive Strength	43 MPa
2	Fineness	5%
3	Standard Consistency	29%
4	Initial Setting Time	30 minutes
5	Final Setting Time	600 minutes

Table 2 – Properties of Fine Aggregate

S. No	Description	Results
1	Size (Passing through)	4.75mm
2	Specific gravity	2.65
3	Bulk Density	1721 kg/m^3
4	Fineness Modulus	30 minutes
5	Final Setting Time	600 minutes

Table 3 – Properties of Coarse Aggregate

S. No	Description	Results
1	Water absorption	0.45
2	Specific gravity	2.68
3	Impact value	14.5
4	Crushing scale	19

Table 4 – Properties of FR4

S. No	Description	Results
1	Water absorption	0.10
2	Density	1850 kg/m^3
3	Temperature Index	140°c
4	Rockwell hardness	110 m Scale
5	Compressive strength (Flatwise)	>415 MPa

3.1.5. Mix Design for M20 AS per ACI (kg/m^3)

Mix design for M30 grade concrete according to BIS method (IS 10262:2009). Added 5% of e-waste is replaced in fine aggregate component plus 10% of fly ash added. The mix proportion for concrete is shown in the Table 5.

Table 5 – Mix Proportion

S. No	Mix ID (% Of FR4 Added)	Cement	F.A	C.A	Flyash (10%)	FR4	Water	W/C Ratio
1	**1 (0%)**	**355**	**800**	**1018**	**35.5**	**0**	**185**	**0.5**
2	**2 (5%)**	**355**	**760**	**1018**	**35.5**	**40**	**185**	**0.5**
3	**3 (10%)**	**355**	**720**	**1018**	**35.5**	**80**	**185**	**0.5**
4	**4 (15%)**	**355**	**680**	**1018**	**35.5**	**120**	**185**	**0.5**
5	**5 (20%)**	**355**	**640**	**1018**	**35.5**	**160**	**185**	**0.5**
6	**6 (25%)**	**355**	**600**	**1018**	**35.5**	**200**	**185**	**0.5**
7	**7 (30%)**	**355**	**560**	**1018**	**35.5**	**240**	**185**	**0.5**
8	**8 (35%)**	**355**	**520**	**1018**	**35.5**	**280**	**185**	**0.5**
9	**9 (40%)**	**355**	**480**	**1018**	**35.5**	**320**	**185**	**0.5**
10	**10 (45%)**	**355**	**440**	**1018**	**35.5**	**360**	**185**	**0.5**
11	**11 (50%)**	**355**	**400**	**1018**	**35.5**	**400**	**185**	**0.5**

3.2. Sequential Methodology

Utmost care had been taken to ensure proper batching and blending of the constituents in Hobart mixer machine to cast cube, cylinder and concrete panels thereafter they are subjected to curing period as per the BIS norms [12-15]. In total 66 cube specimens, 33 cylindrical specimens, 33 slab panels are cast. The specimens are assessed for its mechanical performance in which they are tested in UTM machine having a capacity of 2 tonnes. Especially for concrete panels to compute its thermal insulation, a special electrical setup having a length of 1.5m having a microprocessor board with display unit has been assembled and those panels are placed in the middle of the closed chamber [16-18]. The occupancy sensors are fixed on the either sides of the chamber to measure the liberation of thermal energy. Incandescent lamp is been considered due to its light source. A 100 watt bulb is taken which has an efficiency of 2.1%. The thermal energy produced by the bulb are allowed to intermediate the concrete panel and the readings pertaining to thermal conductivity [19-22].

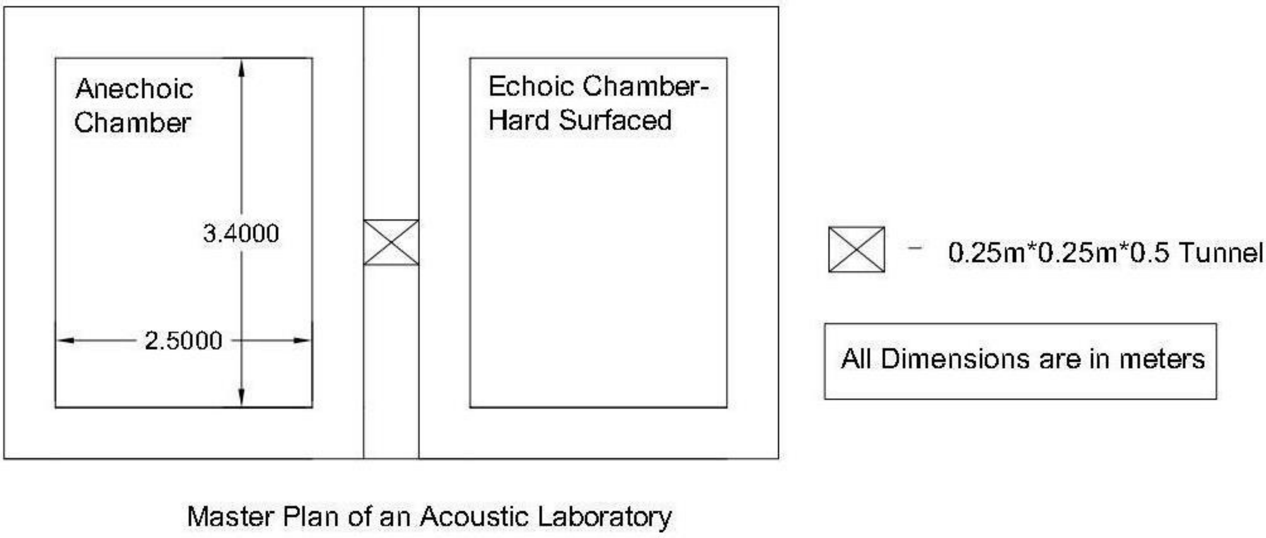
Sound absorption test had been conducted by creating a sharp sound in the hard-surfaced room which was recorder through speakers from Dell laptop utilizing Audacity acoustic software in which the time taken for dissipating the sound intensity say 60 decibels had been measured. A room setup adjacent to non-echoing chamber was insulated completely and covered with sound absorbing material which are designed to scatter and absorb noise. Sabine’s equation, was used to compute the random incidence absorption co-efficient of the concrete panels where the speed of the sound in air had been taken as 343m/s with the following equation

$$\alpha = 55.3V/c\ SA\ (1/T2-1/T1)$$

Random incidence method had been taken to measure sound absorption coefficients. Reverberation time of a chamber was recorded with and without the concrete panels based on the average time from 10 tests with panel as T1 (secs) and without panel as T2 (secs). Fig. 3 shows the plan of an acoustic laboratory.

Sound Insulation is measured by recording the intensity of the sound through concrete panels of varying thickness located in duct between two chambers using low (60 hertz to 500 hertz) an high (1000 hertz to 5000 hertz) frequencies. Initially sound of about 65dB was created in the hardened surface room recorded in anechoic chamber once after passing through the concrete panel where it had been placed into duct surrounded by putty to curb the transmission of sound along the sides of the panel and the procedure was repeated for different thickness of concrete panels. Sound intensity after penetrating the panel was recorded by 2250 light microphone on 1.2m tripod and analyzed in Kjaer type 8400 data recording software.

Fig. 3 - Plan of an Acoustic Laboratory



4. Results and Discussions

4.1. Results and Discussions

The specimens are assessed for its outcomes in terms of compressive, split tensile strength. Outcomes are listed in Table.6. Research study reveals that the maximum compressive strength attained to 25.5 MPa and the maximum split tensile strength attained to 2.55 MPa satisfying the theoretical concept in which 0.1 % of the fracture strength shall attain when adding 20% of FR4 replacing fine aggregate. Thereafter the strength decreased when the percentage of addition had been increased. Hence adding 20% of FR4 shall be considered as the optimum replacement level. Fig.4 shows the variation in compressive strength of conventional & FR4 panels and Fig.5 shows the variation in split tensile strength of conventional & FR4 panels.

Table 6 - Variation in Compressive and Split Tensile Strength

S. No	Mix Id (% of Fr4 added)	Compressive Strength (MPa)		Split tensile strength (MPa)	
		7 Days	28 Days	7 Days	28 Days
1	1 (0%)	21.8	28.3	2.05	2.34
2	2 (5%)	12.22	21.11	1.222	2.111
3	3 (10%)	13.3	22.34	1.33	2.234
4	4 (15%)	15.1	24.5	1.51	2.45
5	5 (20%)	15.5	25.5	1.55	2.55
6	6 (25%)	16.3	21.4	1.63	2.14
6	7 (30%)	11.3	15.6	1.13	1.56
7	8 (35%)	10	14.3	1.18	1.43
8	9 (40%)	8.3	13.86	1.1	1.386
9	10 (45%)	7.87	11.8	1.18	1.18
10	11 (50%)	6.34	10.9	1.09	1.09

Fig. 4 - Variation in Compressive Strength of Conventional & FR4 Panels

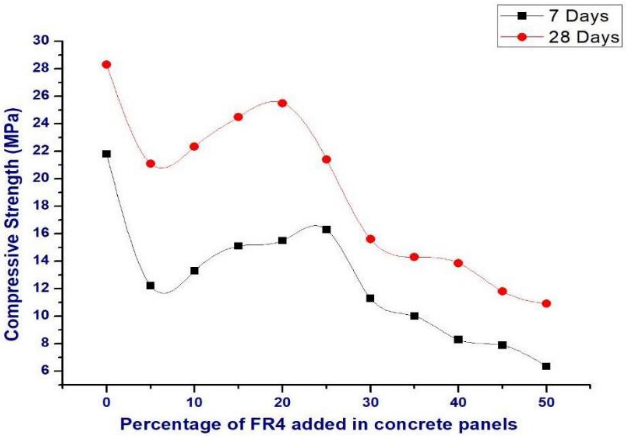


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Fig. 5 - Variation in Split Tensile Strength of Conventional & FR4 Panels

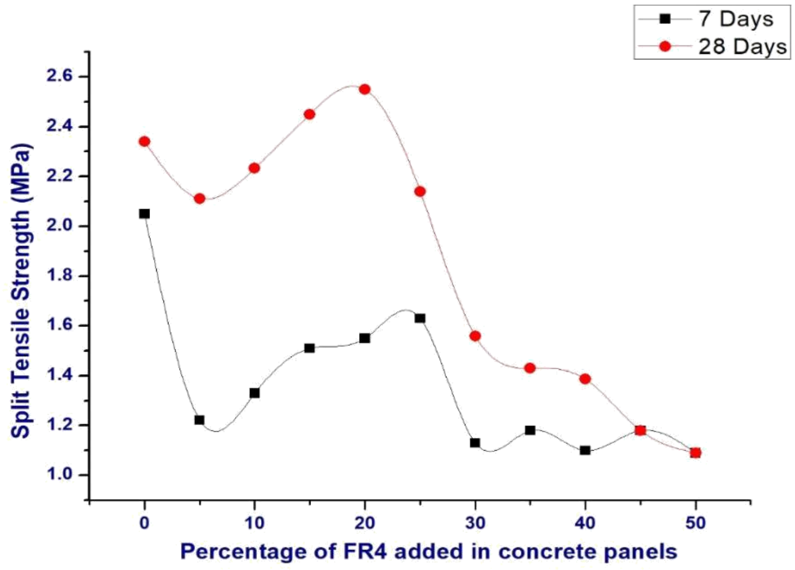

Table 7 – Variation in Thermal Conductivity for Conventional Concrete

S. No	Area (in m2)	Thickness (m)	Time (minutes)	Q/3600 (kj)	Difference in T	Thermal Conductivity (K)	Average K
1	0.09	0.050	5	60	11	3.032	4.933
			10	120	13	5.127	
			15	180	15	6.667	
2		0.075	5	60	12	4.170	6.942
			10	120	14	7.290	
			15	180	16	9.380	
3		0.100	5	60	14	4.760	8.068
			10	120	16	8.330	
			15	180	18	11.110	
4		0.012	5	60	20	4.170	7.372
			10	120	22	7.570	
			15	180	24	10.410	
Overall Average							6.829

With respect to the above Table 7, variation in thermal conductivity had been observed for conventional concrete panels containing FR4 in different thickness levels where the maximum was observed as 8.06 (W/mk) for the concrete panel having 0.10m thickness and the least was observed as 4.9 (W/mk) for the concrete panel having 0.05m thickness.

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Table 8 - Variation in Thermal Conductivity for Concrete Containing FR4

S. No	Area (in m2)	Thickness (m)	Time (minutes)	Q/3600 (kj)	Difference in T	Thermal Conductivity (K)	Average K
1	0.09	0.050	5	60	10	3.340	5.05
			10	120	13	5.130	
			15	180	15	6.665	
2		0.075	5	60	12	4.168	6
			10	120	15	6.515	
			15	180	17	8.824	
3		0.100	5	60	14	4.764	7.70
			10	120	17	7.841	
			15	180	19	10.526	
4		0.012	5	60	21	3.970	6.70
			10	120	24	7	
			15	180	27	9.259	
Overall Average							6.36

With respect to the above tabulation, it is concluded that FR4 panels possess lower thermal conductivity when compared with conventional concrete where the maximum was observed as 7.70 (W/mk) for the concrete panel having 0.10m thickness and the least was observed as 5.05 (W/mk) for the concrete panel having 0.05m thickness [23-26]. Fig. 6 shows the variation in sound absorption coefficient in conventional & FR4 panels, Fig. 7 shows the sound retained (dB) with low frequencies in conventional & FR4 panels and Fig. 8 shows the sound retained (dB) with high frequencies in conventional & FR4 panels.

Table 9 - Sound Absorption Coefficient for FR4 and Control Mix

Sl. No	Mix Id (% of Fr4 added)	Sound Absorption Coefficient of Concrete	
		Conventional	with FR4
1	1 (0%)	0.03	nil
2	2 (5%)	0.027	0.12
3	3 (10%)	0.029	0.14
4	4 (15%)	0.028	0.16
5	5 (20%)	0.026	0.2
6	6 (25%)	0.029	0.17
7	7 (30%)	0.03	0.14
8	8 (35%)	0.028	0.16
9	9 (40%)	0.025	0.14
10	10 (45%)	0.03	0.13
11	11 (50%)	0.03	0.11

Fig. 6 - Variation in Sound Absorption Coefficient in Conventional & FR4 Panels

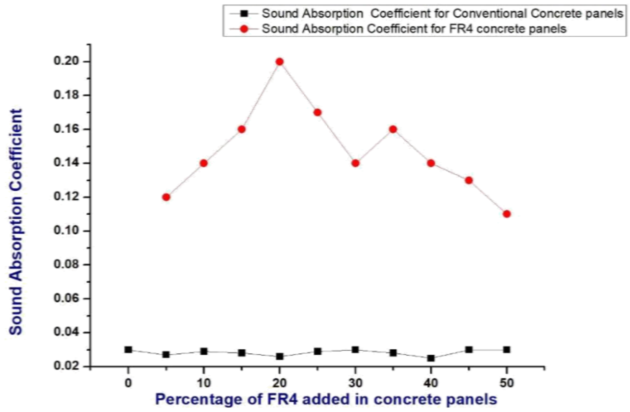


Fig. 7 - Sound Retained (dB) with Low Frequencies in Conventional & FR4 Panels

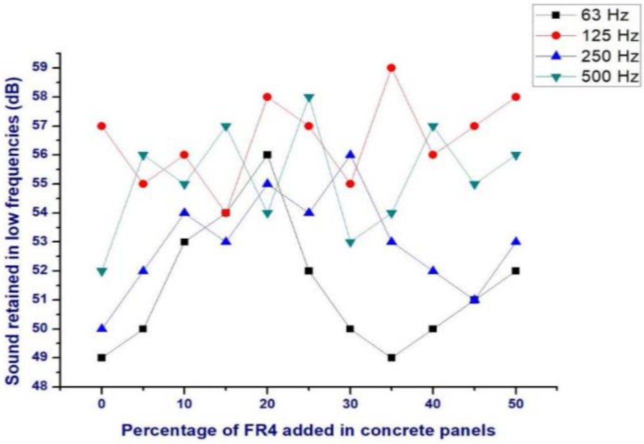
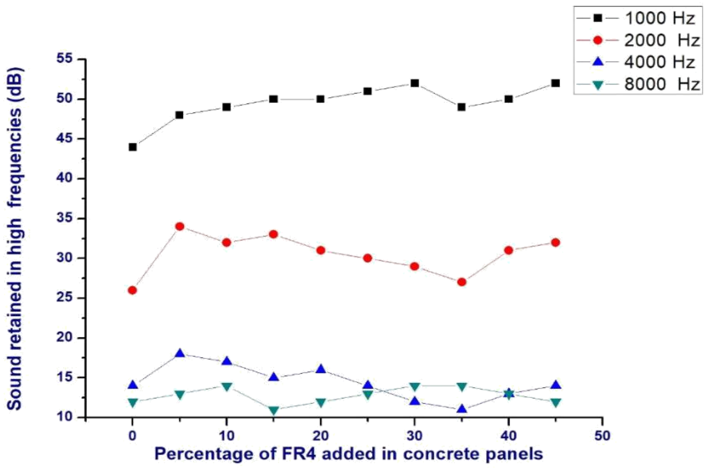


Fig. 8 - Sound Retained (dB) with High Frequencies in Conventional & FR4 Panels



Outcomes pertaining to low and high frequencies of sound insulation tests in concrete panels in laboratory conditions are shown in Fig.7 and Fig.8 respectively [27]. Table 8 shows the variation in thermal conductivity for concrete containing FR4 and Table 9 shows the sound absorption coefficient for FR4 and control mix [28]. With respect to the lower frequencies, the outcomes reveals similar sound insulating properties with the reference identity particularly at 63 Hz and 125 Hz where the extent of sound retained on both ranges approximately 50 and 55 dB. However improved sound insulation properties were observed at higher frequencies [29]. In view towards the lower frequencies, conventional panels seem to be marginally good as an insulating material than FR4 with an average retention of 8dB in the frequency of 2000 Hz yet the rest of the sound retentions are similar to conventional panels in the frequencies say 1000 Hz, 4000 Hz and 8000 Hz. Fig. 9 shows the UPVT test results and Fig. 10 shows the ANSYS output (e-waste) [30].

Fig. 9 - UPVT Test Results

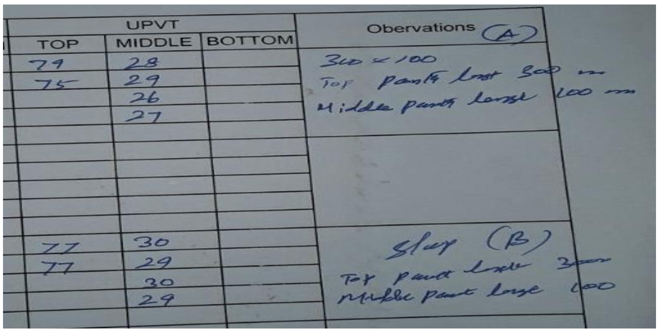
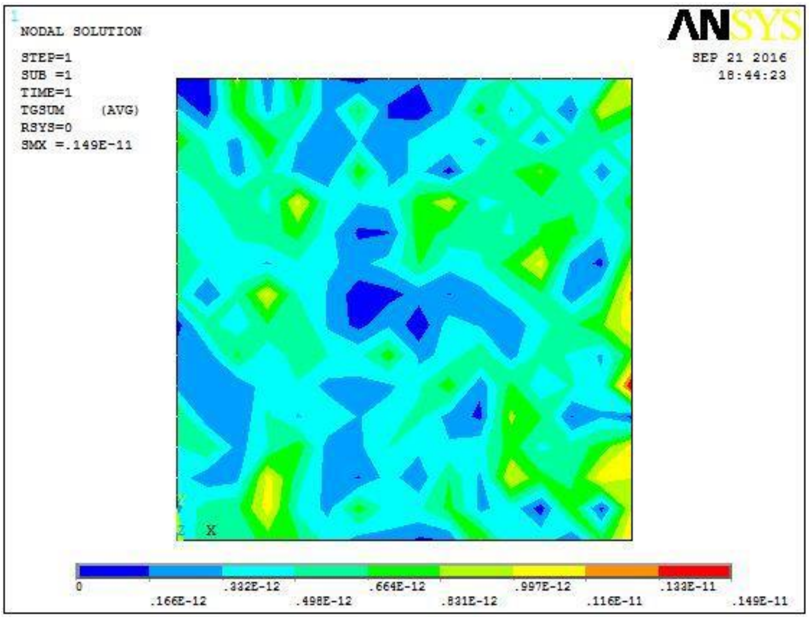


Fig. 10 - ANSYS Output (e-waste)



5. Conclusion

E-waste concrete U factor values are more than the conventional concrete slab with the same area and different thickness. It shows that the R value (heat resistance) for e-waste concrete is lesser than the conventional concrete and the energy stored in the body of e-waste concrete is also lesser than the conventional concrete. So we can prefer e-waste by replacing with fine aggregation portion by 5%. By adding FR-4 to the fine aggregate, it decreases the weight of the concrete and it can provide fine strength and durability like conventional concrete. Moreover, UPVT also shows that the e-waste performs better. Hence, e-waste can be used as an alternative for the fine aggregate portion of conventional concrete.

1. The effective percentage of replacement of fine aggregate by FR4 (E-waste) is of 5% based on the experimental outcomes. However bond interface mechanism has to be studied to understand the rheological properties and due to uneven distribution of FR4 in concrete which was observed.
2. Theoretically, the density of FR4 is slightly lesser than conventional concrete when being replaced with different percentage of fine aggregate. This is an important factor governing the behaviour of sound absorption FR4 (E-waste).
3. The strength of FR4 (E-waste) concrete decreased when FR4 was added in terms of 25% which exhibited significant decrease in workability. However the strength can be maintained provided the replacement level does not exceed 20%.
4. FR4 (E-waste) concrete being replaced in different percentages of fine aggregate has superior sound absorbing properties in higher frequencies when compared with the conventional concrete.
5. FR4 (E-waste) concrete has reduced sound insulating properties when compared with conventional concrete in combination with elevated absorption range which can act as effective noise reduction in urban areas. Despite, FR4 has similar sound reflecting properties when compared with light weight samples.

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