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Accelerated Curing of M30 Grade Concrete Specimen Using Microwave Energy

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ABSTRACT

Compressive strength of concrete mainly depends on the composition, size of the components, water content ratio, curing conditions etc. The 28 days strength is usually taken as reference strength. To find this, a moist curing of concrete specimen for 28 days is required. For economical construction, the 28 days strength is required well in advance and accelerated curing techniques are helpful to some extent. In the conventional accelerated curing, conduction of heat takes place from surface to the core of the concrete specimen and hence there exist a temperature gradient, leading to thermal stress in concrete. In this study, microwave radiation energy is used for accelerated curing in which the temperature change is uniform through out the concrete. The concrete cubes were cured with microwave energy after 6, 18 and 24 h of delay time of M30 grade concrete. Different microwave energy levels (360, 540, 720, 900 W) and microwave curing durations (20, 30, 40, 50 min) were used. The compressive strength developed after the microwave curing is compared with the 28 days strength estimated with the usual procedure. The results obtained were suitably plotted as graphs so that the graphs can be used to estimate the 28 days strength from the early strength obtained by microwave curing. The results of the study show the potential and scope for further research with different grade of concrete.

Key words: Concrete testing, accelerated curing, microwave energy, prediction, compressive strength

INTRODUCTION

The strength of concrete in construction works is determined at its 28 days compressive strength. To find this compressive strength, usually 28 days of moist curing is required. The 28 days of waiting time is too long period for any corrective measure in case the strength is not desirable. That is after 28 days, by the time the quality of concrete is found to be not sufficient, the concrete would have hardened significantly and might be buried by subsequent construction. This makes the replacement of concrete mass of sub-quality concrete very difficult, costly and time consuming. Suppose if the concrete is of greater strength than the required, the uneconomical mix is just a waste of costly material. These indicate a necessity for finding the 28 days characteristic strength for real good quality control. Hence, for better quality control, an accelerated concrete curing procedure is needed which facilitates identifying the 28 days strength in a day or so while the real concrete is still accessible and sufficiently soft to make its removal practicable. Hence, accelerated curing techniques are becoming important.

The concrete takes about 28 days to gain 90% of its strength. When the concrete is not attained sufficient strength, loss of water due to drying of concrete develops tensile strength in concrete which results in cracks. Hence, during this period, the concrete is kept in damp condition. The process of hydration is faster at higher temperatures and hence, gains strength quick (Hutchison *et al*., 1991). However, if the higher temperature leads to evaporation of water from the concrete mass which reduces the strength (Pheeraphan *et al*., 2002; Makul and Agrawal, 2012). Hence, an optimal temperature which less than the evaporation temperature of water is preferred. Accelerated curing techniques use this concept and being utilized in the prefabrication industry enabling earlier removal of the reusable form work that makes business economical. In special situations such as repairing a busy road bridge, accelerated curing is very useful which helps to reduce the detouring time. Curing with steam, curing with warm water curing with boiling water and curing in autoclave are some of the popular methods of accelerated curing.

Usually, conductive heat is used to cure the concrete either in the warm water curing or boiling water curing (IS: 9013, 1978; ASTM C684-99, 2003). This conductive heat flows from the surface of cube specimen to the core thereby creates a temperature gradient (Xuequan *et al*., 1987) and thermal stress in the concrete. This problem can be easily avoided with microwave curing. The microwave heating is due to radiation and the heating is almost uniform through the media in which the microwave passes through.

Microwave was used for curing by few researchers in the last two decades but this has not been explored in detail and thus resulted in fewer innovations (Rattanadecho *et al*., 2008; Makul *et al*., 2009). Some of the literatures which reported the application of microwave energy to mortar or concrete are listed below in Table 1. Many of the researchers used microwave application to the fresh or near fresh concrete to remove excess water which otherwise cause the capillary pores and increased the density of the concrete. It is obvious that the denser concrete can take more compressive load.

Table 1: Details of delay time, microwave duration, watts and water-cement ratio used in previous studies that used microwave energy on concrete or mortar

Concrete/mortar	Delay time (min)	Microwave duration (min)	Watts (W)	Water-cement ratio	References
Geopolymer paste	0	5	90	-	Chindaprasirt *et al*. (2013a)
Geopolymer paste	0	3, 5, 10	90, 180	-	Chindaprasirt *et al*. (2013b)
Concrete	0	0-90	650	0.6	Dongxu and Xuequan (1994)
Mortar	0	15-40	50	0.44	Hutchison *et al*. (1991)
Concrete	1440	20-60	700	0.55	Lee (2007)
Mortar and concrete	30	45	200-700	0.4-0.55	Leung and Pheeraphan (1995a, b)
Mortar and concrete	0, 35	30, 45	100-1200	0.325, 0.35, 0.4, 0.5	Leung and Pheeraphan (1997)
Cement paste	30	45	100-600	0.38	Makul *et al*. (2010)
Cement paste	30	45	180-811	-	Makul and Agrawal (2011)
Cement paste	30	45	390	0.38	Makul and Agrawal (2012)
Concrete	30	45	198-543	0.5	Pheeraphan *et al*. (2002)
Cement paste and mortar	30	120	-	0.4	Sohn and Johnson (1999)
Mortar	720	<120	240	0.4	Somaratna *et al*. (2010)
Mortar	0	15-120	150-650	0.44	Xuequan *et al*. (1987)

In the above listed references, microwave energy is used for different purposes. However, microwave energy used for thermal curing in lieu of the conduction curing is not seen in the literature. Hence, in this study, microwave energy is used for accelerated thermal curing, especially for concrete cubes, to predict the 28 days compressive strength. Many authors applied microwave on cubes of fresh mortar or fresh concrete when they are in the microwave transparent moulds. However, in this study, the objective is to develop a laboratory test procedure and hence the concrete was casted in regular mould and after the concrete was hardened a little so as to handle/move it without mould, they were subjected to microwave curing. This study presents results of part of the on-going larger work which has an objective to develop a laboratory test procedure for testing concrete cubes, reducing curing time by microwave curing. In the present study, results pertaining to M30 grade concrete were analysed and reported and other grade concrete experiments are currently going on.

MATERIALS AND METHODS

Experimental studies on concrete required characterizing the ingredient materials used for making the concrete. Though the usually available materials were used in this study, the experimental results may vary if the materials of different characteristics are used. Hence, as a good practice, the material properties are presented. The Portland-Pozzolana Cement (IS: 1489, 1991) used in this study had specific gravity of 3.18, normal consistency of 32%, fineness of 9%, initial setting time of 28 min and final setting time of 360 min as per IS: 4031 1988. The estimated (IS: 2386, 1963) physical properties of the fine and coarse aggregates used in this study are presented in Table 2. For making the concrete and curing drinking water was used.

ACI method was used to find the mix proportion of concrete to provide M30 grade concrete and mix proportion identified was 1.00 : 2.16 : 2.52 with 0.46 as water/cement ratio. With the given mix, workability of the concrete in terms of slump was 86 mm and compaction factor was 0.87, respectively. Nine numbers of cubes of size 100×100×100 mm were casted as control cubes. To estimate 7, 14 and 28 days strengths, three cubes each were tested in the compression testing machine. Microwave curing was applied after a minimum of 6 h (delay period) after casting. That is the cubes were in the mould at room temperature (28°C) and in a moist environment till the delay period. Microwave energy was applied after the delay period for a duration which is called 'microwave duration'. Commercial available microwave oven (IFB K024), having internal cavity of 390×268×400 mm with output power option of 20, 40, 60, 80 and 100% of full output power of 900 W, was used. During microwave curing, cube was kept in a water bath in a microwave-transparent container. After microwave curing, the cubes were allowed to cool for about 30 min and then tested for compression as per IS: 516, 1959 specifications.

Table 2: Characteristics analysis of fine and coarse aggregates used in this study

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.69	2.94
Void ratio	0.80	0.40
Porosity (%)	41.50	40.00
Fineness modulus	2.40	7.20

RESULTS AND DISCUSSION

Many researchers listed in Table 1 used microwave application to fresh or near fresh concrete to remove excess water and thus increased the density of the concrete. Along with early strength development, Lee (2007) used microwave energy in freeze-thaw durability study. Though microwave energy is used for different purposes, it is not used for thermal curing in lieu of the boiling water or hot water curing of concrete. Hence, in this study, microwave energy is used for accelerated thermal curing, especially for concrete cubes, to predict the 28 days compressive strength.

For each batch, 3 specimens are tested and the average result was taken for the analysis and presentation of results in the graphical form. Out of the three samples in a batch, if one provides a compressive strength which is deviating abnormally from the average, the test was repeated. The results were presented in the form of figures (Fig. 1a-f). In the figures and text, the delay period is denoted as D, the microwave curing duration is denoted as M. Similarly, sa, s7, s14 and s28

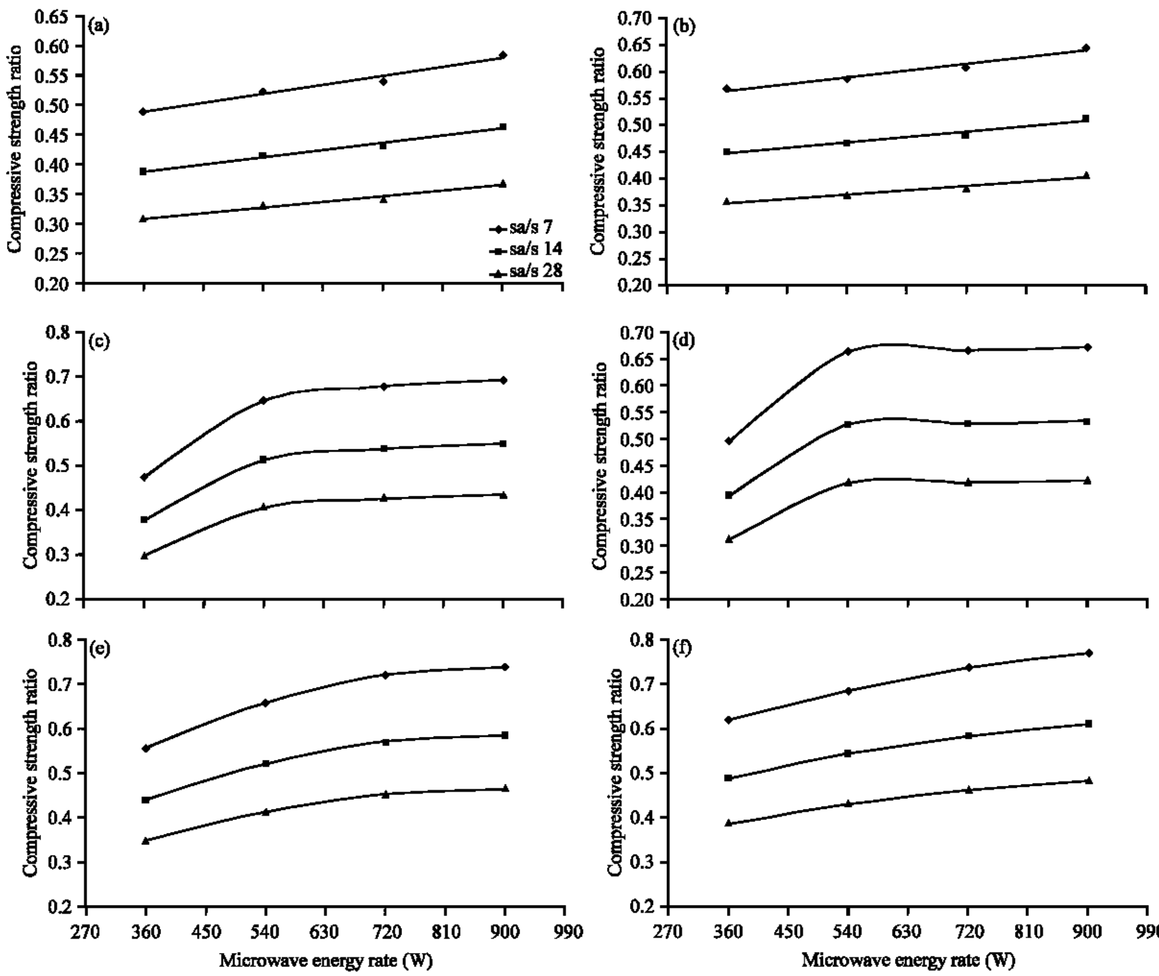

Fig. 1(a-f): Relationship between microwave energy rate and compressive strength for different D and M (a) D = 18 h and M = 30 min, (b) D = 18 h and M = 50 min, (c) D = 24 h and M = 20 min, (d) D = 24 h and M = 30 min, (e) D = 24 h and M = 40 min and (f) D = 24 h and M = 50 min indicate compressive strength obtained by accelerated curing, 7 days compressive strength obtained by regular curing, 14 days compressive strength obtained by regular curing and 28 days compressive strength obtained by regular curing, respectively. In all the experiments conducted, the accelerated curing never exceeded 80% of the 7 days compressive strength by regular curing. Hence, the ratios sa/s 7, sa/s 14 and sa/s 28 are all less than one. The experiments were conducted 18 and 24 h delay periods. In all three cases of delay period, ±30 min of delay period is allowed because of the practical limitations.

From Fig. 1a-b, it can be observed that for a delay period of 18 h, the increase in microwave power increases the compressive strength almost linearly for both 30 and 50 min microwave curing durations. However, the Fig. 1c-f indicate that for 24 h delay period and lower microwave curing duration of 20 and 30 min, the strength gain is faster with respect to lower microwave energy rates of 360-540 W. After 540 W, the strength gain is not much with the increase in microwave power; further, as the microwave curing duration increases, the strength gain turns to become almost linear with increase in microwave power. As discussed earlier, many researchers used microwave application to fresh or near fresh concrete to remove excess water or for thawing in the 'freeze-thaw durability' study. However, microwave energy was not used for thermal curing of concrete. Since, this present study is new of its kind, the findings of this study could not be compared with previously published studies either in support or in contradiction.

CONCLUSION

The results obtained through this study can be used for earlier identification of 28 days compressive strength through microwave curing. For example, assume a 10 cm cube M30 grade is cast and cured in microwave oven after a delay period of 18 h (D = 18 h) for a period of 50 min (M = 50 min) at 900 W and the compressive strength is observed as 12.4 Mpa. For the given D and M and microwave power, as per the Fig. 1b the sa/s 28 is 0.4. Therefore, sa/s 28 is sa/0.4 = 12.4/0.4 = 31 Mpa. This reduces the time of identifying the compressive strength from 28 days to less than 24 h. In this study, only M30 grade concrete was used and the usefulness of microwave based accelerated curing was shown. However, generating a bigger database with different grade concretes, with more number of specimens and wider range of parameters and developing regression relationships will be useful for the construction industry.

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