ICOCEE
3. International Conference on Civil and Environmental Engineering
Çesme - Turkey

3. ICOCEE – CESME, April 24-27, 2018
Editors: S. Sahinkaya, E. Kalipci, M.C. Bagdatli

Effect of Microwave Curing on the Strength Development of Mortars Produced with Fly Ash and Plasticizer

İlker Bekir Topçu*[1], Hüseyin Hakan İnce[2] and Cenk Karakurt[3]

[*1] Eskişehir Osmangazi University, Department of Civil Engineering, TURKEY.
(E-mail: ilkerbt@ogu.edu.tr)

[2]Mehmet Akif Ersoy University, Department of Civil Engineering, TURKEY.
(E-mail: hakanince@mehmetakif.edu.tr)

[3]Bilecik Şeyh Edebali University, Department of Civil Engineering, TURKEY
(E-mail: cenk.karakurt@bilecik.edu.tr)

ABSTRACT

The microwave curing method increases the strength gaining of mortars and concrete at early ages due to the accelerated hydration reactions of the cement. The early age strength values obtained from microwave cured cementitious composites can be associated with the strength values at later ages. Thus, it is possible to estimate the strength of the concrete at the later ages. In this study, two different types of cement, two different types of plasticizer admixtures and F-type fly ash were used for specimen production. The compressive strength tests were carried out after a portion of the prepared mortar specimens had been exposed to microwave accelerated curing while the rest of them had been cured in water for 7 days as well as 28 days. Any linear relationship determined between the compressive strengths of the plasticizer added specimens, and also the 7 and 28-day compressive strengths were evaluated and thereby, estimation of the 7 and 28-day day compressive strengths of the specimens were aimed. Taking the reliability levels and margins of error into account, it was observed that the microwave accelerated curing method yielded more reliable results especially in terms of estimating the compressive strengths in polycarboxylate added mortar specimens.

Keywords: Fly ash, Microwave curing, Mortar, Plasticizer, Strength prediction.

INTRODUCTION

The primary fact of the quality of concrete, which is one of the most widely employed building materials in this day and age, as well as the designing stages of reinforced concrete structures, is the 28-day compressive strength. The fact that this particular compressive strength measure of a concrete can only be determined directly in 28 days after its production always constitutes a practical problem and it is widely acknowledged as a significant disadvantage for concrete (Christopher et al., 1995). High quantities of concrete could be

produced during the course of an idle 28-day period required to determine the conformity of the concrete's compressive strength with the particular class strength requirements (Hutchison et al., 1991). As a result, there is an ultimate need for determining the quality of a freshly produced concrete at the shortest possible period of time after its production (Pheeraphan et al., 2002).

Microwave curing is mainly employed for practical purposes such as the removal of excess water in mortar and concrete; improving early strength of mortar; measuring the water content as well as the amount of non-vaporizing water, hence the degree of hydration in mortar; and finally the quality control in concretes via early determination of compressive strength (Sohn et al., 1999). Microwave energy may also be utilized for curing of mortar and concrete due to the inherent water content (Akdağ, 2007). Microwaves are absorbed by the water molecules which exhibit a polarized molecular structure and thus provide a mechanism of heat generation within the cement, and that heat enables the mortar to attain strength earlier by accelerating the hydration of cement (Rattanadecho et al., 2008) Thanks to the homogenous distribution of water molecules within the mortar, the heat generation takes place uniformly throughout the mortar in microwave curing method and consequently, heating of the mortar occurs rapidly and homogeneously (Topçu et al., 2008).

Since the specimen is subjected to hydration homogenously during the application of microwave curing, the whole process of hydration is quite similar to its course in standard curing. As a result, the hydration processes of the main cement components do not interfere with one another and the components hydrate in a way that would not allow the formation of a structure that hinders each other. This whole procedure leads to the formation of a more stable microstructure. As a result of the entire process, a reliable correlation can be established between the early strength and later age strength. In the studies conducted on microwave curing, it was observed that the early age strength values obtained through microwave curing can be used for the estimation of 7 and 28-day standard compressive strengths (Topçu et al., 2008; Uğurlu, 2008). However, the particular components and admixtures in the mortar can obviously create deviations in the strength estimates (İnce, 2012). Hence, in this study, the linear relationships determined between the compressive strength values of polycarboxylate-based and polynaphthalene-based plasticizer added specimens obtained by microwave curing and the 7 and 28-day compressive strengths were compared against each other, and finally the estimation of 7 and 28-day compressive strengths of the specimens was attempted.

MATERIAL AND METHODS

Materials

In the experimental mix design CEM I 42.5 R type Portland cement was supplied from Göltaş Cement factory. Çatalağzı Thermal Power Plant Type F Fly ash (FA) is used as a mineral additive in mortar mixtures. Standard CEN mortar sand is used as fine aggregate in mortar production (TS EN 196-1). Two different types of plasticizer are used in mortar mix design with a chemical composition as polycarboxylate (H) based and polynaphthalene (S) based. Properties of cement, fly ash and plasticizer admixtures used in the experiments are given in Table 1-2. The polycarboxylate-based and polynaphthalene-based admixtures were used in the mortar mixtures at proportions of 1% and 2%. The fly ash was used in replacement ratios with 10%, 20% and 30% by weight of cement.

Table 1. Properties of cement and fly ash used in experiments

Chemical composition (%)	CEM I 42.5	FA
SiO_2	19.87	58.63
Al_2O_3	4.11	26.03
Fe_2O_3	3.44	6.12
CaO	63.65	1.17
MgO	1.61	2.50
SO_3	2.68	0.19
Na_2O	0.12	0.47
K_2O	0.48	4.75
LOI	2.89	1.10
Cl^-	0.008	0.016
Physical properties		
Specific gravity (g/cm^3)	3.16	2.00
Blaine fineness (cm^2/g)	3440	2580

Table 2. Properties of plasticizer admixtures used in experiments

Plasticizer	pH	Density (kg/dm^3)	Recommended dosage	% Water Retention
Polycarboxylate-based	6 - 8	1.082 - 1.142	0.5 - 1.5%	> 40
Polynaphthalene-based	6.5 - 8	1.17 - 1.23	0.6 - 3.0%	12 - 25

Method

Mortar bar specimens are produced in dimension with 40x40x160 mm. The ratios of water/binder/sand [W/(C+FA)/S] were taken as 0.5/1/3 in plasticizer-free specimens, and as 0.35/1/3 in plasticizer added specimens (Table 3). The compressive strength tests were carried out after a portion of the prepared specimens was subjected to microwave accelerated curing, and the rest was cured by soaking in water at a temperature of 20±1 ^oC for 7 and 28 days in accordance with TS EN 196-1 (2016) standard.



Figure 1. Microwave curing with special teflon moulds

Table 3. Mix design of mortar specimens.

Specimen	$\frac{w}{C+FA}$	Cement (gr)	FA (gr)	Water (gr)	Sand (gr)	Plasticizer (gr)
Reference	0.50	450	0	225	1350	0
FA10	0.50	405	45	225	1350	0
FA20	0.50	360	90	225	1350	0
FA30	0.50	315	135	225	1350	0
Reference (H)	0.35	450	0	158	1350	4.5
FAH10	0.35	405	45	158	1350	4.5
FAH20	0.35	360	90	158	1350	4.5
FAH30	0.35	315	135	158	1350	4.5
Reference (S)	0.35	450	0	158	1350	9
FAS10	0.35	405	45	158	1350	9
FAS20	0.35	360	90	158	1350	9
FAS30	0.35	315	135	158	1350	9

Specially designed Teflon molds were utilized for exposing the specimens to microwave curing, which was applied to each specimen as per the following procedure; a pre-dwell period of 90 minutes, followed by three 15-minute sessions of microwave curing totally 45 minutes, with 10-minute resting intervals in between them (Figure 1). Additionally, the curing was conducted such that the early strength test would be carried out at 8 hours.

RESULTS AND DISCUSSION

The 7 and 28-day strength estimation equations and the correlation curves derived from the early strength observations of the specimens subjected to microwave accelerated curing, which had been devised to predict the 7 and 28-day strengths of normally cured specimens, are presented in Figures 2-5.

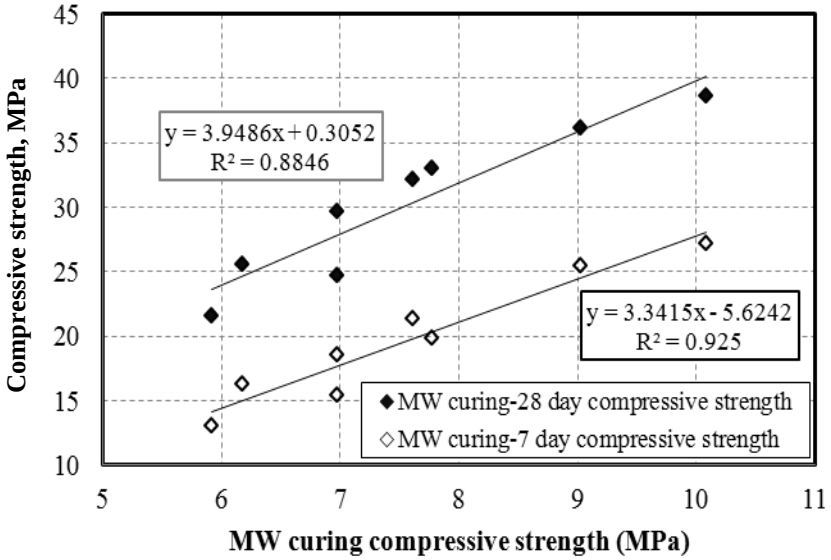


Figure 2. The strength relationship of plasticizer-free (F) specimens

As seen in Figure 2 the degree of reliability (R) values for the 7 and 28-day compressive strengths were respectively as follows; 92% and 88% in plasticizer-free specimens.

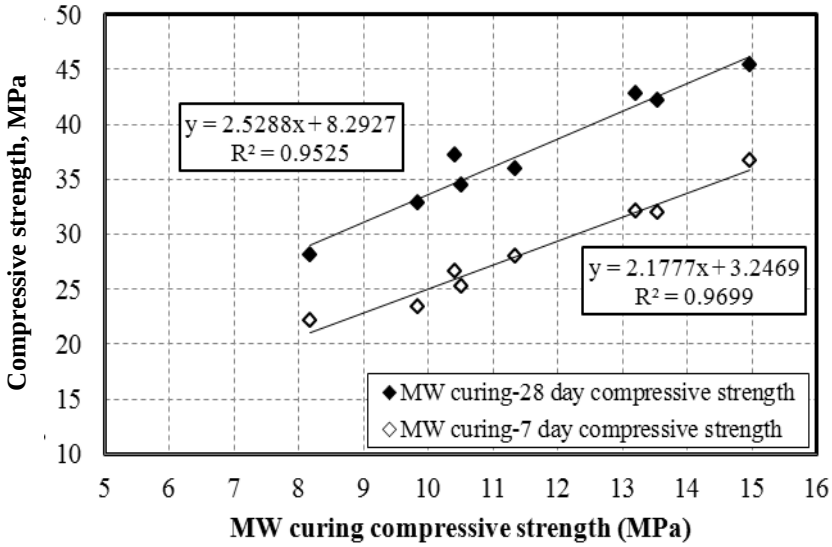


Figure 3. The strength relationship of polycarboxylate plasticizer added (H) specimens

The degree of reliability (R) values for the 7 and 28-day compressive strengths were respectively as follows; 97% and 95% in polycarboxylate plasticizer added specimens as shown in Figure 3.

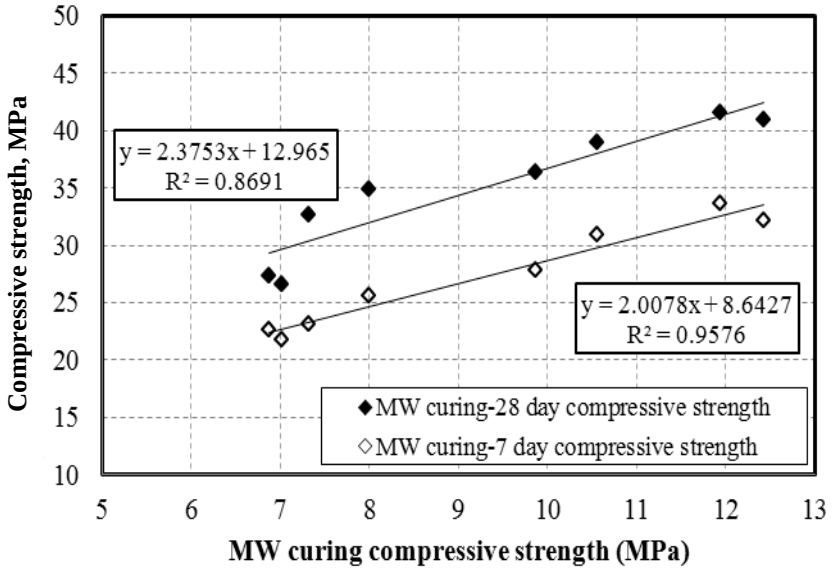


Figure 4. The strength relationship of polynaphthalene plasticizer added (S) specimens.

As seen in Figure 4 the degree of reliability (R) values for the 7 and 28-day compressive strengths was respectively as follows; 95% and 87% in polynaphthalene-based plasticizer added specimens. Finally, the degree of reliability (R) values for the 7 and 28-day compressive strengths were respectively as follows; 85% and 84% for all of the specimens as shown in Figure 5. In order to demonstrate the relationship between the data derived from the established equations and the experimental data as clearly as possible, the minimum, maximum and mean values for absolute errors as well as the geometric mean of errors were determined and displayed in Table 4.

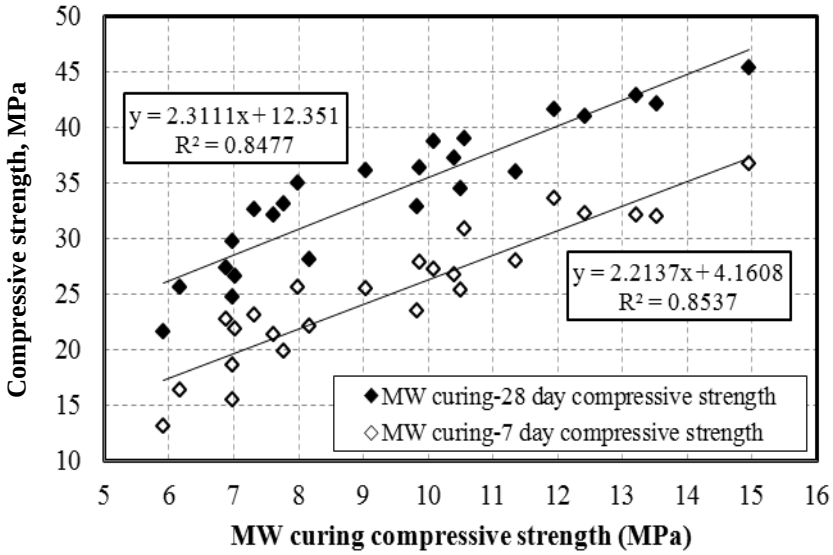


Figure 5. The compressive strength relationship of all specimens

The prediction errors with respect to the estimated values for the 7-day and 28-day compressive strengths turned out to be as follows, respectively; the geometric mean of error is 0.58% and 0.56% in F specimens, 0.05% and 0.13% in H specimens, 0.12% and 0.43% in S specimens, and1.32% and 0.51% in all specimens; whereas the mean absolute errors were 6.40% and 6.06% in K specimens, 2.62% and 2.58% in S specimens, 2.86% and 5.09% in S specimens, and 8.67% and 6.63% in all specimens. Assessing the mean error values for the 7-day and 28-day compressive strength estimates, it is seen that the H specimens had lower values of mean error compared to the other types of specimens and turned out to have more accurate estimates.

Table 4. Calculated errors

Type of Error		F Specimens		H Specimens		S Specimens		All Specimens	
		7-day	28-day	7-day	28-day	7-day	28-day	7-day	28-day
Geometric Mean of Error		0.58	0.56	0.05	0.13	0.12	0.43	1.32	0.51
Absolute Error	Minimum	2.29	0.48	0.02	0.87	0.97	0.19	0.53	0.06
	Mean	6.40	6.06	2.62	2.58	2.86	5.09	8.67	6.63
	Maximum	14.52	12.86	5.23	7.09	4.41	11.16	31.85	20.34

At the previous studies in the literature, it is shown that there is a relationship in between 7 and 28 days compressive strengths relevant to microwave cured compressive strengths obtained and also, 7 and 28 days compressive strengths can be predicted. Topçu et al. (2008) found out at their study that, the reliability of microwave curing results for 7 and 28-day water curing of mortars are 98% and 91% for Portland Cements (Type I) and at 91% and 84% for fly ash added cement respectively.

Pheeraphan et al. (2002) showed at their studies on concretes prepared with rapid-hardening Portland cement that, 7-day compressive strengths of specimens can be predicted by using compressive strengths of microwave cured specimens with a ± 13% margin of error and a 0.95 reliability degree.

Reliability degrees of 7-day compressive strengths obtained by using microwave cured early strengths are bigger than those obtained from 28-day cured ones as can be seen from Figures 2-5. It can be commented that 7-day compressive strength values of mortars form in a narrow range whereas 28-day strengths show difference for obsolescence.

CONCLUSION

In order to predict the 7 and 28-day standard compressive strengths of the mortar specimens, various equations were derived for the plasticizer-free, polycarboxylate-based plasticizer added, polynaphthalene-based plasticizer added as well as the entire groups of specimens utilizing the observations on the microwave cured specimens. The compressive strengths obtained from these equations were compared with the 7 and 28-day compressive strengths of the mortar specimens. In consideration of the reliability levels and margins of error, it was observed that the microwave curing method yields more reliable results with respect to the estimation of compressive strengths of polycarboxylate-based plasticizer added specimens. In addition, plasticizer-free and polynaphthalene added specimen's yielded similar results. Evaluating the entire group of specimens as a whole, the reliability levels of 7 and 28-day strengths were found to be 85% and 84%, respectively, whereas the mean error values were determined as 8.67% and 6.63%. From the obtained results, it was concluded that the microwave curing method allows the prediction of 7 and 28-day standard compressive strengths of mortar specimens based on the 8-hour compressive strengths measured after the application of microwave accelerated curing, and also that it would be more convenient to conduct separate assessments within particular groups of mortars based on the types of admixtures used.

References

Akdağ, D. 2007. *Determination of Optimal Cure Cycle by Using Accelerated Microwave Cure on Mineral Admixture Mortars*, M.Sc. Thesis, Department of Civil Engineering, Eskişehir Osmangazi University, Institute of Science, Eskişehir, Turkey.

Christopher, K., Leung, Y., Pheeraphan, T. 1995. Microwave curing of Portland cement concrete: experimental results and feasibility for practical applications. *Construction and Building Materials*, **9**, 67-73.

Hutchison, R.G. Chang, J.T., Jennings, H.M. and Brodwin, M.E. 1991. Thermal acceleration of Portland cement mortars with microwave energy. *Cement and Concrete Research*, **21**, 795-799.

İnce, H.H. 2012. *Effect of Accelerated Curing by Microwave on Blended Mortars*, Ph.D. Thesis, Department of Civil Engineering, Süleyman Demirel University, Institute of Science, Isparta, Turkey.

Pheeraphan, T., Cayliani, L., Dumangas, M.I. and Nimityongskul, P. 2002. Prediction of later-age compressive strength of normal concrete based on the accelerated strength of concrete cured with microwave energy. *Cement and Concrete Research*, **32**, 521-527.

Rattanadecho, P., Suwannapum, N., Chatveera, B., Atong D. and Makul, N. 2008. Development of compressive strength of cement paste under accelerated curing by using a continuous microwave thermal processor. *Materials Science and Engineering: A*, **472**, 299-307.

Sohn D., Johnson, D.L. 1999. Microwave curing effects on the 28-day strength of cementitious materials. *Cement and Concrete Research*, **29**, 241-247.

Topçu, I.B., Toprak, M.U. and Akdağ, D. 2008. early prediction of concrete strength using microwave curing method. *IMO Technical Bulletin*, **19**, 4539-4544.

Topçu, I.B., Toprak, M.U. and Akdağ, D. 2008. Determination of optimal microwave curing cycle for fly ash mortars. *Canadian Journal of Civil Engineering*, **35**, 349-357.

TS EN 196-1. 2016. *Methods of testing cement - Part 1: Determination of strength*, Turkish Standards Institute, Ankara, Turkey.

Uğurlu, A. 2008. Application of accelerated curing by the method of microwave energy. *Journal of Concrete Prefabrication*, **88**, 13-20.