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The Effect of Microwave Curing on the Strength Development of Class-F Fly Ash-Based Geopolymer Mortar

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Abstract: This study investigates the influence of microwave (MW) curing on the strength development of geopolymer. Since applying conventional oven heat curing makes the heat move from the outer edge to the center of the specimen, it leads to a non-uniform of distributing heat within the specimen, which affects the mechanical properties of the geopolymer. On the other hand, the use of MW reduces the curing time and allows uniform heat distribution within samples, and provides higher mechanical properties in a short period. The influence of conventional heat curing and MW curing on class F fly ash based geopolymer activated with sodium hydroxide and sodium metasilicate was investigated. The conventional heat curing was applied at 75 and 90°C for 6 and 24 hours; on the other hand, additional MW curing was applied for a different period (5-60 minutes) and different energy level (100, 180 and 300W) on hardened geopolymer samples cured with conventional oven curing. The results show that the use of conventional heat curing for 6 hours, followed by MW curing, gave higher or equivalent strength compared to only conventional heat curing. While 24 hours conventional heat curing results with a geopolymer having 39.1 MPa compressive strength, 6 hours conventional heat curing followed by 1 hour MW curing at 180W energy level results with a geopolymer with compressive strength in the order of 80 MPa.

Mikro Dalga Kürünün F Sınıfı Tabanlı Geopolimer Harçların Dayanım Gelişimine Etkisi

Anahtar Kelimeler
Uçucu kül,
Geopolimer,
Mikrodalga kürü,
Dayanım

Öz: Bu çalışmada, mikrodalga (MW) kürünün geopolimerin dayanım gelişimi üzerindeki etkisi araştırılmıştır. Geleneksel ısıyla fırın küründe, ısı numunenin dış kenardan numune merkezine doğru hareket etmekte ve bu durum numune üzerine üniform olmayan bir ısınmaya neden olarak geopolimerlerin mekanik özelliklerini etkilemektedir. Öte yandan, MW kullanımı numuneler içinde homojen ısı dağılımına olanak sağlayarak kürleme süresini azaltmakta ve kısa sürede daha yüksek mekanik özellikler elde edilmesini sağlamaktadır. Çalışmada sodyum hidroksit ve sodyum metasilikat ile aktive edilmiş F sınıfı uçucu kül bazlı geopolimerler üzerinde geleneksel ısıl kür ve MW kürü etkileri araştırılmıştır. Geleneksel ısıl kür 75 ve 90°C'de 6 ve 24 saat süreyle numunelere uygulanmıştır. Mikrodalga kürü ise geleneksel ısıl kür ile kürlenen sertleştirilmiş geopolimer numunelere farklı süre (5-60 dakika) ve farklı enerji seviyelerinde (100, 180 ve 300W) ilave olarak uygulanmıştır. Elde edilen sonuçlara göre 6 saat boyunca geleneksel ısıl kür ile sertleşen numunelere MW kürü uygulanması durumunda, yalnızca geleneksel ısıl kür ile dayanım kazanan numunelere kıyasla daha yüksek veya eşdeğer bir dayanım elde edildiği görülmüştür. 24 saat geleneksel ısıl kür sonucu 39,1 MPa basınç dayanımına ulaşan bir geopolimer, 6 saat geleneksel ısıl kür sonrası 180W enerji seviyesinde 1 saat MW kürüne tabi tutulduğunda 80 MPa civarında basınç dayanımı elde edilmiştir.

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1. Introduction

Over the last decades, it has seen an increasing interest in the production of cement and its effect on the environment. However, 8% of world carbon dioxide emits from factories that produce cement. Since every ton of produced cement emits about 0.65 to 0.95 tons of CO_2 considering the using of fuel and the clinkering processes and the type of cement. In the production of cement, about 55% of the emission comes in the stage where $CaCO_3$ (limestone) turns to CaO (lime) and about 40 % of CO_2 emission comes from the combustion processes needed to reach 1450 C°[1].

Furthermore, common drawbacks of conventional concrete like the low resistance against acids, salts and low fire and thermal resistance (over 500 °C). So, finding new alternative material is desirable. One of the alternative substitutes for cement-based binders is geopolymers.

Geopolymers, in general, are inorganic materials that are produced by activating alumina-silicate materials such as fly ash, natural pozzolans, zeolite, etc. by alkaline solutions (activator) such as sodium hydroxide, potassium hydroxide, water glass (potassium silicate solution) and sodium carbonate.

The reaction starts with the dissolution of aluminate and silicate from origin material then gelation and intensification forming silico-aluminates with a 3D network. The activation requires heat as an external energy source in order to form alkali alumino-silicates. In order to get good mechanical and physical properties for the fly ash geopolymers heat curing increases in the range of 30°C to 90°C [2]**.**

Geopolymers provide:
-In compressive strength wise provide high compressive strength. [3]
-Good resistance properties against fire [4–6].
-High resistance for different salt solutions and acids. [7]
-High resistance to sulfates. [8]
Also, the production cost of geopolymers comparing to that of cement is considerably lower due to the reuse of post-consumer wastes and industrial byproducts as a partial or full replacement for the Portland cement and reduce the emission of CO_2 [4], [9].

However, geopolymers applications were limited because they need a long heat curing time (4-96 hr.) [2] also, applying conventional heat curing makes the heat moves from the outer edge to the center and leads to a non-uniform of distributing heat within the specimens, which effects on the mechanical properties of the geopolymer. On the other hand, the using of MW reduces the curing time and allows to uniform heat distribution within samples, where the heating process occurs within the sample on the molecular level [10].

MW heating is done by generating an electromagnetic wave with a range of frequency of 300 MHz to 30 GHz, then the interaction of specimen molecules with the electromagnetic field leads to convert the electromagnetic energy to thermal energy. This thermal energy will affect by improving the kinetics of the reaction and leads to an increase in the gaining of the strength [10].

This study investigates the effect of conventional and MW curing on the strength development of geopolymer activated with different activators. Also, temperature development has been investigated.

2. Material and Method

2.1. Fly ash

In this research, class F type fly ash was used with the amount of total $SiO_2 + Al_2O_3 + Fe_2O_3$ is higher than 70%, and the amount of CaO is lower than 10% which according to EN 450-1 [11] and ASTM C618 [12] as low lime ash (class F fly ash). Specific gravity and specific area of fly ash were 2.39 g/cm^3 and 3000 cm^2/g respectively [13]. Chemical compositions of fly ash were presented in Table 1

Table 1. The chemical composition of fly ash used

Oxide %	SiO	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
Fly ash	61.81	19.54	7.01	1.77	2.56	0.31	2.43	0.99	2.2

2.2. Water

In preparation of mortar tap water taken from the city, supply was used.

2.3. Sand

Rilem-Cembureau Standard sand was used in the preparation of the mortar mixture. Grading of CEN standard sand was given in Table 2.

Table 2. Grading of CEN standard sand

Sieve size (mm)	2	1.6	1	0.5	0.16	0.08
Cumulative %	0	7	33	67	87	99
Standards %	0	7 ± 5	33 ± 5	67 ± 5	87 ± 5	99 ± 1

2.4. Sodium Hydroxide

The chemical composition of sodium hydroxide (NaOH) used in the mixture is given in Table 3.

Table 3. The chemical composition of NaOH that used for activating geopolymer

Oxide %	NaOH	Na_2CO_3	Cl	SO_4	Pb	Al	Fe
NaOH	≥ 97	≤ 1	≤ 0.01	≤ 0.01	≤ 0.002	≤ 0.002	≤ 0.002

2.5. Sodium Metasilicate

The chemical composition of sodium metasilicate used in the mixture was given in Table 4.

Table 4. The chemical composition of Sodium Metasilicate used for activating geopolymer

Molar ratio	Weight ratio	SiO_2	Na_2O
0.94	0.91	44.94	49.38

2.6. Microwave

For MW curing household commercial microwave (Samsung MW71B) was used with a range of power 100-800W and frequency of 2.45 GHz. The microwave oven used for MW curing was given in Figure 1.

Figure 1. Microwave used for MW curing

2.7. Infrared thermometer

The temperature of the sample surface measured using an infrared thermometer (BM380) with an emissivity of 0.95 and measuring range (-32~550℃). Figure 2 shows the infrared thermometer used for temperature measurement.

Figure 2. Infrared thermometer [14]

2.8 Mixture preparation

Fresh geopolymeric mortar mixtures were prepared using fly ash, sand, water and alkali activator. Mixture proportions in a mass basis were 1; 3; 0.3; fly ash, sand, water, respectively. The sodium amount used was 10% of fly ash amount in a mass basis. Alkali solution was prepared using sodium hydroxide and sodium metasilicate separately. For the mixture that was activated with sodium hydroxide, the alkali solution was prepared by mixing sodium hydroxide with water (80 g of sodium hydroxide with 135 g of water were mixed and the solution was left to cool down for one day), then alkali solution was mixed with 450 g of fly ash for 30 s, and 1350 g of sand was added to the mixture and mixed for 4 minutes in a mixer. The mixture was molded and vibrated for 2 minutes in a prismatic mold for compaction.

On the other hand for the mixture that was activated with sodium metasilicate, the mixture was prepared by mixing 120 g of sodium metasilicate with 450 g of fly ash manually for several seconds in dry condition, then 160 g of water was added to mixture and mixed for 30 s, consequently 1350 g of sand was added to mixture and mixed for 4 minutes. The fresh mixture was molded and vibrated for 2 minutes in the three-cell prismatic mold for compaction. Mixture proportions of geopolymeric mixtures were presented in Table 5, for three-cell prismatic mold which molds three 40x40x160 mm^3 prismatic samples.

Table 5. Mix proportion of mortar

Mixture	Fly ash (g)	Activator (g)	Water (g)	Sand (g)
Sodium hydroxide	450	80	135	1350
Sodium metasilicate	450	120	160	1350

2.9 Conventional curing

The control geopolymer samples were cured in a conventional way for 6 and 24 hours at 75 and 90°C at the laboratory oven. After oven curing control samples were cooled down to room temperature in the laboratory environment then strength testing was carried out.

The geopolymer mortar samples to be cured in MW oven were cured 6 hours by oven curing to obtain a hardened sample at 75^0C and 90^0C temperature, separately. Oven curing time of 6 hours was obtained by pre-trial oven curing. Lower oven curing duration (i.e. 5 hours or lower) result with a softer sample that could not be handled for de-molding. After curing in an oven for six hours, these samples were cured in MW oven for some period presented in the following section.

2.10 Microwave curing

Fly ash based geopolymer mortar samples activated with NaOH after 6 hours of conventional curing, the samples were cured in MW oven for 5, 10, 15, 30, 45, and 60 minutes at 100, 180, and 300W of MW energy. After additional MW curing the samples were cooled down to room temperature which was about 22°C before strength testing. During MW curing due to the very high energy level of 300W, MW curing time was stopped at 30 minutes.

The samples activated with sodium metasilicate and cured in oven for 6 hours, were additional cured in MW oven for 5, 10, 15, 30, 45, and 60 minutes at only 180W of MW energy, since 180W energy level was found to be optimal and applicable energy level that was obtained from the results of geopolymer samples activated by sodium hydroxide.

2.11 Flexural Strength

Flexural strength test was performed according to TS EN 1015-11 standards [15], in flexure test 40x40x160 mm^3 samples were used. The flexural test performed under three-point loading and opening between supports was 100 mm. The flexural strength result was obtained by taking the average of three prismatic specimens.

2.12 Compressive Strength

The compressive strengths were obtained using two broken prismatic parts obtained from the flexural strength test. The compression test was applied according to TS EN 196-1 standard [16]. The compressive strength result was obtained by taking the average of six pieces with a loading area of 40x40 mm^2.

3. Results

3.1 Compressive and Flexural Strength development of NaOH activated geopolymer

a. Compressive strength of conventional cured mortar

Compressive strengths of NaOH activated geopolymer samples cured in a conventional oven for 6 and 24 hours at 75 and 90°C were shown in Table 6. It can be observed from Table 6 that, the increase in temperature from 75 to 90°C leads to an increase in the compressive strength of geopolymer which is found to be in line published materials [10], [17]–[20]. Also, an increase in curing time from 6 hours to 24 hours results with an increase in compressive strength supporting literature findings [21]. Six hours oven curing at 75°C, result with a compressive strength in the order of 5 MPa. However, 24 hours oven curing results with 36 MPa compressive strength. Moreover, six hours oven curing at 90°C, result with a compressive strength in the order of 25 MPa. However, 24 hours oven curing results with 40 MPa compressive strength.

Table 6. Compressive strength of oven geopolymer samples activated with NaOH (MPa)

Time (hour)	75^0C	90^0C
6	5.4	24.0
24	36.0	39.1

b. Compressive strength development of MW cured mortar after 6 hour oven curing

Compressive strength of NaOH activated geopolymer mortar samples cured additionally with microwave oven was presented in Table 7 and Table 8. These compressive strengths were obtained from samples cured for 6 hours in conventional curing at 75^0C and 90^0C and followed additional MW curing for different time duration as well as different MW energy level. Table 7 presents the compressive strength of additional MW cured samples after 6 hours at 75^0C oven curing.

Table 7. Compressive strength of MW cured samples after 75°C oven curing (MPa)

Time (min.)	100 W	180 W	300 W
5	5.4	8.2	9.5
10	5.4	8.3	32.2
15	5.8	13.3	64.0
30	6.7	32.0	67.2
45	11.7	66.0	NA
60	11.3	77.0	NA

Table 7 shows that the use of 100 W of MW power leads to slow development in compressive strength. Until 30 minutes, 100W energy level did not influence strength development, significantly. Furthermore, application of MW curing for 45 and 60 minutes at 100W level increased compressive strength of the sample, nearly doubled the strength values in comparison to 30 minutes curing, however, strength value was in the order or 10 MPa.

It can be observed from Table 7 that the influence of the application of 180W level MW curing on strength development was not very high until 10 minutes curing time, however, it becomes visible for 15 minutes MW curing. MW curing for 30 minutes at 180W level developed 32 MPa compressive strength, which is comparable to 24 hours conventional oven curing results, 36 MPa. Furthermore, 45 and 60 minutes MW curing at 180W level developed 66 MPa and 77 MPa compressive strength values, respectively.

Influence of MW curing at the 300W level on compressive strength of geopolymer mortar becomes visible even for 5 minutes curing time compared to 6 hours oven curing. Application of MW curing for 10 minutes at 300W developed 32 MPa compressive strength that was comparable to 24 hours oven curing result. Moreover, 15 minutes curing time at 300W level gave 67 MPa compressive strength that was equivalent to the results of 45 minutes curing at the 180W level. However, 30 minutes curing time at 300W did not improve strength much, in comparison to 15 minutes at 300W. It should be noted that applying MW curing longer than 30 minutes at 300W caused some disturbing cracking noises and spallings were observed on samples. MW power of 300W and higher energy levels lead to an increase in the temperature in the sample above 100°C (boiling temperature for water), which leads to rapid evaporation that might cause internal stress and pores [22] as shown in Figure 3. Subsequently, 45 and 60 minutes MW curing at 300W level was not carried out.

Figure 3. The effect of 300 W of MW curing on the sample after 30 minutes [14]

Table 8 presents the compressive strength of additional MW cured samples after 6 hours at 90°C oven curing. It can be seen from Table 8 that until 15 minutes MW curing at the 180W energy level, compressive strength development of geopolymer mortar was not visible, since 6 hours oven curing developed 24 MPa strength, and 15 minutes MW curing increased this value to 26 MPa. However, increasing MW curing time to 30, 45 and 60 minutes result with a significant increase in compressive strength and the values become 34 MPa, 71 MPa and 79 MPa, respectively, which means 42%, 200% and 233% increase in compressive strength in comparison to only 6 hours oven curing compressive strength. On the other hand application of MW curing at 300W level, 5 and 10 minutes additional curing, improved the compressive strength of samples an average of 25% and 30%, in comparison to 6 hours counterpart reference geopolymer. However, 15 minutes curing time result with high strength at about 60MPa which means more than 100% increase in compressive strength compared to 6 hours oven curing. Furthermore, 30 minutes MW curing gave 66 MPa compressive strength.

Table 8. Compressive strength of MW cured samples after 90°C oven curing (MPa)

Time (min.)	180 W	300 W
5 min.	25.6	29.0
10 min.	25.9	32.4
15 min.	26.0	58.0
30 min.	34.6	66.0
45 min.	71.6	NA
60 min	79.5	NA

Comparison between 24 hours oven curing result and MW curing at 180W and 300W showed that 300W level energy catches 24 hours curing results at 10-15 minutes of MW curing application, while 180W energy level catches 24 hour oven curing results at about 30 minutes of MW curing time. Based on these observation and results obtained, it was concluded that the increase in curing time of MW heating increased compressive strength. It was found that 180W MW energy level was optimal and applicable energy level for MW curing application. In such a

short time about 7 hours, meaning 6 hours conventional oven curing followed by 1 hour MW curing at 180W level developed high compressive strength from fly ash based sodium hydroxide activated geopolymer mortar. Also, it can be concluded that the final strength of samples was not significantly influenced from initial oven temperature. Compressive strengths of samples cured additionally one hour at the 180W energy level, cured initially at 75^0C and 90^0C before MW curing, were 77 MPa and 79 MPa, respectively. Similarly, they were 67 MPa and 66 MPa for 300W energy level at 30 minutes MW curing time. This efficient compressive strength development attributed to MW curing that provides uniform distribution of heat within the sample and improves the geopolymerization and increases the strength of geopolymer in a short period.

c. Flexural strength of Conventional cured mortar

Flexural strengths of reference control samples cured with conventional heat curing for the different temperatures at 75^0C and 90^0C for 6 hours and 24 hours curing duration were presented in Table 9. The flexural strength of samples cured at 75^0C for 6 hours was 1.3 MPa, it was 5.3 MPa for 90C temperature curing. Applying 24 hours heat curing increased flexural strength in comparison to 6 hours curing.

Table 9. Flexure strength of control samples activated with NaOH (MPa)

Time (hour)	75^0C	90^0C
6	1.3	5.3
24	6.7	7.7

d. Flexural strength of MW cured mortar after 6 hours oven curing

Geopolymer mortar samples activated with sodium hydroxide and cured for 6 hours at 75^0C temperature were additionally cured with MW oven and flexural strength of samples were presented in Table 10.

Table 10. Flexural strength of samples cured at 75°C followed by MW curing (MPa)

Time (min.)	100 W	180 W	300 W
5	1.3	2.9	2.3
10	1.4	2.9	6.1
15	1.6	3.6	13.3
30	2.4	4.5	12.3
45	**3.9**	11.0	NA
60	3.9	12.8	NA

It can be seen from Table 10 that 100W energy level of MW curing for 5 minutes did not improve flexural strength compared to only oven curing for 6 hours. However, an increases in MW curing time improved flexural strength. Improvement was found to be similar to compressive strength development. MW curing of specimens for 60 minutes developed 3.87 MPa flexural strength for 100W energy level. Moreover, the application of MW curing for 180W energy level, significantly improved flexural strength starting from 5 minutes to 60 minutes, the flexural strength of 5 minutes MW curing was 2.9 MPa while control was 1.3 MPa. Increasing MW curing time to 60 minutes developed 12.8 MPa flexural strength. Similar flexural strength was obtained from 300W energy level for 15 – 30 minutes MW curing time. It should be noted that the highest flexural strength value obtained in this study is in the order of 13 MPa which was considered in the literature as high flexural strength.

Geopolymer mortar samples activated with sodium hydroxide and cured for 6 hours at 90^0C temperature was additionally cured with MW oven and flexural strength of samples were presented in Table 11.

It can be seen from Table 11 that the flexural strength development trend during MW curing was found to be similar to its counterpart compressive strength for samples cured initially at 90^0C prior to MW curing application. This was valid for both energy levels of MW, 180W and 300W.

MW curing at 180W energy level developed such flexural strength in the order of 14 MPa for 60 minutes MW curing time. However, MW curing at 300W for 30 minutes gave 11 MPa flexural strength.

Table 11. Flexural strength of samples cured at 90°C followed by MW curing (MPa)

Time (min.)	180 W	300 W
5	5.4	5.5
10	5.7	6.3
15	6.5	11.5
30	6.8	11.5
45	12.3	NA
60	13.6	NA

3.2. Compressive and Flexural Strength Development of Sodium meta-silicate activated geopolymer

a. Compressive strength of conventional cured mortar

Compressive strengths of sodium metasilicate activated geopolymer samples cured in an oven for 6 and 24 hours at 75 and 90°C were shown in Table 12. Table 12 shows that, the increase in temperature from 75 to 90°C caused an increase in the compressive strength of geopolymer which is found to be in line published [10], [17]–[20] Also, increase in curing time from 6 hours to 24 hours results with an increase in compressive strength supporting literature findings [21]. The compressive strength of sodium metasilicate activated fly ash based geopolymer was found to be satisfactory even at 6 hours oven curing which is 30 and 44 MPa for 75^0C and 90^0C temperature, while they were 63.2 and 65.1 MPa for 24 hour oven curing, respectively. Comparison between oven cured compressive strength of geopolymer mortar activated with sodium hydroxide and sodium metasilicate shows that compressive strength of sodium silicate activated geopolymer was superior to the compressive strength of sodium hydroxide for both temperature 75^0C and 90^0C and for curing time 6 and 24 hours (see Table 6 and Table 12). Higher oven curing temperature result with higher compressive strength. Longer oven curing time provided higher compressive strength.

Table 12. CS of oven cured geopolymer samples activated with sodium metasilicate (MPa)

Time (hour)	75^0C	90^0C
6	30.1	44.8
24	63.2	65.1

b. Compressive strength development of MW cured mortar after 6 hours oven curing

Compressive strength of geopolymer mortar cured by additional MW curing after 6 hours oven curing was presented in Table 13, at 75^0C and 90^0C temperature. As it was mentioned above that curing with the 180W energy level in MW curing was found to be optimal level, sodium metasilicate activated geopolymer mortar samples were cured at only 180W energy level for different MW curing duration.

A close observation of Table 13 shows that additional MW curing application increased the compressive strength of geopolymer mortar in comparison to only 6 hours oven curing. It could be stated that 30 minutes additional MW curing was found to be adequate for sodium metasilicate activated geopolymer since compressive strength of samples did not show any more development after 30 minutes MW curing time. This curing time developed at about 65MPa compressive strength from sodium metasilicate activated geopolymer mortar. After 30 minutes of MW curing, some reduction was observed in compressive strength. This reduction could be due to long curing time leads to a high temperature which causes moisture loss which is causes micro-cracks in the sample that leads to a reduction in the compressive strength[10].

However, for both initial oven curing temperature 75^0C and 90^0C, maximum compressive strength was in the range of 65MPa, which could be accepted as high compressive strength.

Table 13. Compressive strengths of 180 MW cured samples after 75^0C and 90^0C oven curing (MPa)

Time (min.)	75^0C	90^0C
5	32.7	46.0
10	34.4	46.1
15	51.1	46.8
30	65.5	63.4
45	61.2	58.7
60	59.8	56.3

c. Flexural strength of Conventional cured mortar

Flexural strengths of reference control samples activated with sodium metasilicate and cured with conventional oven curing at 75^0C and 90^0C for 6 hours and 24 hours curing duration were presented in Table 14. The flexural strength of samples cured at 75^0C for 6 hours was 6.8 MPa, it was 9.4 MPa for 90^0C temperature curing. Applying 24 hours heat curing increased flexural strength in comparison to 6 hours curing. For both temperature curing 24 hours oven curing developed flexural strength in the order of 10 MPa.

Table 14. Flexure strength of control samples activated with sodium metasilicate (MPa)

Time (hour)	75^0C	90^0C
6	6.8	9.4
24	10.4	10.2

d. Flexural strength of MW cured mortar after 6 hours oven curing

Geopolymer mortar samples activated with sodium metasilicate and cured in a oven for 6 hours at 75^0C at 90^0C temperature were additionally cured with 180 MW and the flexural strength of samples were presented in Table 15.

Table 15. Flexural strengths of 180 MW cured samples after 75°C and 90°C oven curing (MPa)

Time (min.)	75^0C	90^0C
5	7.4	9.1
10	7.6	8.6
15	8.4	9.1
30	10.6	10.2
45	12.3	11.6
60	10.2	11.0

It can be seen from Table 15 that 5 minutes additional MW curing did not significantly improve flexural strength in comparison to only oven curing for 6 hours for both initial curing temperatures. However, the increase in MW curing time significantly improved flexural strength. Improvement was found to be similar to compressive strength development. MW curing of specimens for 45 minutes developed 12.3 MPa and 11.6 MPa flexural strength, for 75^0C and 90^0C initial oven curing temperature, respectively.

3.3. Temperature profile

Variation of temperature profile on the surface of a MW cured geopolymer sample was measured. This measurement was not carried out for all specimens, and mixture, and MW energy levels. It was carried out on a sample for a specific mixture, at the 180W energy level, since 180W energy level was found to be the practical and optimal value. Temperature profile development was measured on three prismatic samples and an average of three measurements were taken as temperature measurements. Temperature variations on samples for different MW curing duration were given in Table 16.

Table 16. Temperature development for 180 W of MW energy of samples cured 6 hours in oven at 75°C

Time (min.)	180 W
5	83
10	101
15	107
30	115
45	147
60	152

Table 17 shows temperature on the surface of samples reaches to 83C in 5 minutes. It increases as MW curing time increases and it gets 152C for 60 minutes of MW curing application. The increase in temperature profile was found to be parallel to the development of strength properties, as the temperature increases the compressive strength and flexural strength of geopolymer mortar increases.

4. Discussion and Conclusion

Following conclusions were made from the laboratory study.
1-It was concluded that 100W energy level of MW curing was not sufficient. However, the optimal energy level for MW curing was found to be 180W for proper strength development of geopolymer mortar.

2-MW curing at 180W energy level for one hour curing duration results in compressive strength in the order of 80 MPa for NaOH activated geopolymer. In the same manner, it results with flexural strength in the order of 13 MPa.

3-MW curing at a 180W energy level for thirty minutes hour curing duration results from a compressive strength in the order of 65 MPa for sodium metasilicate activated geopolymer. In the same manner, it results with flexural strength in the order of 11 MPa.

4-Although, there was a significant difference between the strength of six hours oven cured samples at the initial curing temperature of 75^0C and 90^0C, there was no significant difference between 24hours oven cured strength of geopolymer samples. Moreover, there was no significant difference between the final strength of additional MW cured samples initially cured at 75^0C and 90^0C. This is valid for each activator separately.

5-NaOH activated geopolymer mortar developed higher strength than that of activated sodium metasilicate samples.

6-NaOH activated geopolymer samples needed sixty minutes additional MW curing, while sodium metasilicate samples needed thirty minutes to develop optimal highest strength.

7-It was found that 300W energy level for MW curing is dangerous and not practical, since it cracks and explodes samples due to very high MW energy.

8-Temperature profile development and strength development were found to be in line, and they support that higher temperature results with more geopolymeric reaction and higher strength.

9-MW curing treatment can considerably reduce heat curing time of geopolymer sample.

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