# A Review of Cement Mortars Exposed to Elevated Temperatures

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**Abstract**

Cement mortars are one of the popular composite materials that are used for various purposes in construction industries. Many investigations were conducted over the past few decades with the aim of enhancing its characteristics. Fire resistance is one of these important fields since fire is one of the most dangerous situations for buildings and it has many and different causes such as arson, electrical short circuit, lighting, etc. Therefore, the purpose of this paper is conducting a review of the previous studies on the mechanical properties of cement mortars subjected to elevated temperatures. These studies were examined and explained in a chronological narrative style. Researchers, in general, have inspected the influence of adding/replacing materials in cement mortars such as fly ash, superplasticizer, nanosilica, etc. Compressive and flexural strengths were the most examined parameters. In addition, cooling methods and their influence on fire resistance were also considered.

**Keywords**: Cement mortars, Composite materials, Fire resistance, Compressive strength, Flexural strength.

# مراجعة المونات الأسمنتية المعرضة لدرجات حرارة مرتفعة

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**الخلاصة**

مونة الأسمنت هي أحد المواد المركبة الشائعة التي تستخدم لأغراض مختلفة في صناعات البناء. تم إجراء العديد من الأبحاث على مدى العقود القليلة الماضية بهدف تعزيز خصائصها. تعتبر مقاومة الحريق أحد هذه الخصائص حيث أن الحريق من أخطر المواقف بالنسبة للمباني وله أسباب عديدة ومختلفة مثل الحرق المتعمد والدائرة الكهربائية القصيرة والإضاءة وما إلى ذلك. لذا فإن الغرض من هذا البحث هو إجراء مراجعة الدراسات السابقة على الخواص الميكانيكية لمونة الأسمنت المعرضة لدرجات حرارة مرتفعة. تم مراجعة هذه الدراسات وشرحها بأسلوب سرد زمني. قام الباحثون بشكل عام بفحص تأثير إضافة / استبدال المواد في مونة الأسمنت مثل الرماد المتطاير والملدنات الفائقة والنانوسيليكا وما إلى ذلك. كانت قوة الانضغاط والانثناء هي أكثر الخواص التي تم فحصها. بالإضافة إلى ذلك ، تم النظر في طرق التبريد وتأثيرها على مقاومة الحريق

**الكلمات المفتاحية:** مونة الأسمنت ، مواد مركبة ، مقاومة الحريق ، مقاومة الانضغاط ، قوة الانحناء.

## 1. Introduction

Numerous researches and studies were conducted regarding construction methods and materials over the years with the objective of producing structures that fulfil with "Cost-effective" characteristics [1]. One of these methods requires is combining two or more different materials producing a composite material that has improved performance and characteristics than its component individually. Over the years, composite materials have received huge success in the construction industry since they combine low density with high strength, thus providing stronger and lighter products [2].

There are numerous usages for composite materials in construction such as employing them as binding (mortar) materials. As the name suggests, these materials are with cohesive and adhesive characteristics and which are used to bind building blocks such as stones and bricks. One of the earliest evidence of using binding materials in construction is in the sixth century BC where the Babylonian used bitumen as a binder for their gypsum and plaster construction. The Egyptians also used mortars made from clay and mud to build their pyramids and later employed the gypsum and lime mortar instead. Later in 300 BC, the Romans introduced a new binder that is manufactured from lime and volcanic ash called pozzolan, which is a hydraulic mortar that hardens when mixed with water [3]. However, one of the strongest materials for making mortar is Portland cement was introduced first in 1824 by Joseph Aspdin. Cement mortars are made by mixing cement, sand and water in the desired proportions. What distinguishes it from lime mortars that it hardens quickly, hence allowing a faster construction pace. Furthermore, it doesn't require skilled workers. Many inspections were conducted by researchers in order to improve cement mortars. However, investigating the structural performance of the cement mortar under various elevated temperatures is one of the most important and crucial ones. Therefore, the purpose of this paper is conducting a literature review on the mechanical properties of the cement mortar under various elevated temperatures.

## 2. Literature review

Fire is considered one of the most dangerous situations for domestic, commercial and industrial buildings, and numerous and various researches were conducted in order to improve the fire-resisting performance for construction materials including cement mortar.

Sobolev and Yeğinobali (2005) [4] have investigated the development of high-strength cement mortars with elevated temperature and acid resistance using granulated blast furnace slag and silica fume as additive materials. 12 samples with different mixtures were prepared for experimental tests. 2 samples were used as control models. As for the remaining 10, the granulated blast furnace slag content was 50%, while the silica fume's varies between 5% and 15%. In addition, Three different superplasticizers were used, polyacrylate polymer-based hyperplasticizer (HP), melamine-formaldehyde sulphonate (SMF), and naphthalene formaldehyde sulphonate (SNF). Each mixture was cast into 3 prism moulds with dimensions of 40 x 40 x 160 mm. the moulds were placed (after mortar compactions) for 24 hours in a humidity cabinet (90% - 95%) at 20 °C, and the samples (removed from moulds) were placed in water. After 28 days the samples were tested for thermal resistance by heating them in an oven (up to 800 °C). Moreover, the water absorption was determined by using oven-dry samples (100 °C). It was found that the mortars modified with granulated blast furnace slag, silica fume and HP demonstrate a better fire-resistance (100 - 700 °C); furthermore, their compressive strength has improved at 200-300 °C. As for water absorption, the mentioned samples have achieved lower rates by up to 10 times when compared to the control models.

Menou et al. (2006) [5] have inspected cement mortars in the manner of their residual fractural energy when subjected to high temperatures. High strength mortar with silica fume was used and 3 notched beam models (100 x 100 x 400 mm) were employed for experimental tests. The models have undergone a cycle of heating and cooling (at 20, 120, 250, and 400 °C) with an optimized speed in order to avoid any temperature gradient damages. After that, they were examined using a three-point bending testing machine. The load has been gradually applied until it reached its maximum value, and in order to obtain a stable crack propagation, the loading valve was slightly closed after that. It was observed that by exposing the cement mortar to elevated temperature, the fracture energy remarkably increases by approximately up to 50% when compared to the room temperature.

Hossain et al. (2006) [6] have considered the heat resistance performance of cement mortars containing high volume fly ash without employing water reducing agent. 5 specimens with different mixture were used, and the cement has been replaced by fly ash from 30% to 70%. They have been cast into 2-inch cube moulds and were kept in a wet place for 24 hours for curing. Thereafter, the specimens were subjected to various temperatures from 25°C to 600°C. It was concluded that bond and compressive strengths of cement mortar improve with increasing the heat until 200°C., after that, it started to decrease.

Aydın and Baradan (2007) [7] have investigated the fire resistance of cement mortars with the presence of fly ash and pumice. 4 specimens with different mixtures (the fly ash content between 0 and 60 %) were prepared and were cast into prismatic steel moulds with dimensions of 40 x 40 x 160 mm, and after curing they were subjected to high temperatures from 300 to 900°C for three hours. After that, the specimens were divided into two groups where the first group has been gradually cooled by leaving them in lavatory conditions and the second one has rapidly cooled by soaking them into water. Once they were cooled, the specimens were examined by flexural and compressive strength tests. It was demonstrated that employing fly ash has positive influence by enhancing the compressive strength by approximately 19% at 900°C (air-cooled), while the sample without fly ash has lost about 68% of its compressive strength at the same degree. However, all samples have displayed a reduction in flexural strength which is as a result of the microcracks and brittle microstructure which is more vulnerable to tensile stress. Besides, the samples that were water-cooled have suffered a significant decrease in strength than the air-cooled ones. This is because of the thermal shock of the hot samples which led to the creation of microcracks.

Aydın (2008) [8] has studied the development of high-temperature cement-based mortars using ground granulated blast furnace slag (GGBFS) and pumice aggregate. Five different mixtures have been prepared. The first mixture has no GGBFS and was considered the control model. The remaining four, on the other hand, the cement was replaced by GGBFS by different percentages (20%- 80%). 12 specimens of each mixture were cast into prismatic steel moulds (40 x 40 x 160 mm), and were exposed to high temperature (300-900°C) in an oven. The specimens were cooled using two different methods, one set was soaked into the water, while the reaming set was left to slowly cool in laboratory conditions. After cooling they were subjected to flexural and compressive strength tests. It was found that the replacement ratio of GGBFS, temperature levels and cooling method greatly influence the fire resistance performance of the mortar. For example, up to 600°C, no compressive strength loss was shown for air-cooled samples with GGBFS content. Water-cooled samples, on the other hand, has suffered a considerable compressive strength loss. This was as result of two phenomena, the first is the increase of water saturation, and the second is the conversion of free calcium hydrate to CaO when exposed to 400-500°C heating, and later converting to $Ca(OH)_2$ when rehydrated, thence causing an increase in volume. As for flexural strength, there was a slight decrease at 300-600°C for air-cooled specimens with GGBFS content above 40%, while the water-cooled samples have suffered a decrease in flexural strength with the increasing of GGBFS replacement ratio. However, increasing the ratio has improved both the flexural and compressive strength at 900°C for both cooling methods.

Morsy et al. (2008) [9] have investigated the influence of silica fume and metakaolin on the composite strength of cement mortars under high temperatures. 18 mortar mixes were employed in this investigation. The first mix has no additive materials and was labelled as the control mortar. The rest have different metakaolin and/or silica fume content (0-30%). The mixes were cast in 50 x 50 x 50 mm cube moulds and were removed after 24 hours. Thereafter, they soaked in water for curing purposes until the testing day where they have been exposed to high temperatures (200 - 800°C) for 2 hours in an electric furnace. It was noticed from the test results the compressive strength of all samples increases as the heat rises until 200°C where it starts to decrease. Furthermore, the sample with 20 % cement replacement ratio where both silica fume and metakaolin (10% each) are used has the highest compressive strength during the heat treatment. The second in favour is the mortar with 30 % cement replacement ratio and have 5 % metakaolin and 25 % silica fume. In conclusion, both of silica fume and metakaolin have a positive influence on the fire-resistance of mortars.

Özge et al. (2008) [10] have studied the influence of high temperature on cement mortars with the presence of fly ash, natural pozzolan, and slag. 6 specimens with different mixtures were prepared and poured into 4 x 4 x 12 cm moulds and were cured for 28 days. Then they were subjected to high temperatures from 150°C to 900°C. It was shown when comparing compressive strengths that mortars samples with pozzolan and fly ash and the ones with slag has the highest fire-resistance (especially at 300°C) than the other samples. As for flexural strength, the influence of mortar mixture becomes trivial after 450°C. In other words, blended cement mortars demonstrate a better performance than the plain ones (without additions).

Ibrahim et al. (2011) [11] have inspected the effect of silica fume on the fire-resistance of cement mortars. Samples with different water/binder ratios (0.4, 0.5, and 0.7) and silica fume replacement (0, 5, and 10%), and in order to compensate the workability losses caused by the silica fume, the superplasticizer was added in the ratio between 0.8 and 3%. 28 specimens were prepared for each mixture and were cast into steel moulds with dimensions of 40 x 40 x 120 mm. The samples were air-dried for 7 days after curing, and later they were heated in the oven at 300°C and 600°C for 24 hours. After cooling in laboratory temperature, the samples were tested for compressive strength. It was demonstrated that the samples with silica fume has higher compressive strength at 300°C when compared to non-silica-fume samples. At

600°C, however, both types of samples (with and without silica fume) shows a significant decrease in compressive strength, yet, the silica fume samples still has greater strength than the non-silica-fume ones.

Yazıcı et al. (2012) [12] have researched the effect of pumice, silica fume and fly ash on the composite strength of cement mortars under elevated temperatures. 13 mortar specimens with different materials mixtures were prepared in this investigation. The pumice, silica fume and fly ash content are different for each mixture (0 - 20 %). 50 $mm^3$ cube moulds were employed to cast the specimens. Thereafter, they were cured (at 20°C) for 7, 28 and 90 days. The specimens were examined by placing them in the laboratory ceramic oven and exposing them to 150,300, 450, 600, and 750°C temperatures, and they were subjected to a heating-cooling period of 24 hours. It was established form the results that elevated temperature has less impact on compressive strength for mortars with pozzolanic materials (fly ash) when compared to ones without additive materials (control mortars). However, Silica fume mortars have the highest compressive strength during the heating process, while pumice mortars have the lowest compressive strength values.

Morsy et al. (2012) [13] have studied the mechanical properties of nano-metakaolin cement mortars subjected to high temperatures. 4 different mixtures were applied. The first mixture has ordinary Portland cement (OPC) by 100%. The rest has the OPC been replaced by nano-metakaolin by 5, 10 and 15%. The samples were cast in 40 x 40 x 160 mm moulds for flexural strength test and 50 $mm^2$ cubes for the compressive strength test. After curing periods, they were dried in an oven (at 105°C) for 24 hours. Then they were exposed to 250, 450, 600, and 800°C for 2 hours. The samples were left to cool at room temperature and later they were tested. It was demonstrated that the sample with 5% nano-metakaolin has a higher compressive strength value than one without. This is due to the increased density of the mortar, and due to the extra calcium silicate hydrate (CSH) which is the results of pozzolanic reaction between nano-metakaolin and CH. However, for samples with 10% and 15 % nano-metakaolin, the compressive strength has decreased. This is attributed to the decrease of C2S and C3S phases in cement, and due to hindrance of the nano-metakaolin to the hydration process, thus, weakening the bond between grains. As for the temperature tests, it can be seen that both flexural and compressive strengths increase at 250°C, and they start to decrease after that. However, the decrease is less with nano-metakaolin samples. In other words, applying the right quantity of nano-metakaolin can optimize the fire resistance performance of cement mortars.

Ibrahim et al. (2012) [14] have conducted a study regarding the effect of adding nanosilica on the elevated temperature resistance of the cement mortars with fly ash. 10 different mixtures were employed in this study. The first mixture has no fly ash or nanosilica content and was considered to be the reference sample. The rest have various Fly Ash percentage (25-45%), various nanosilica percentage (2.5-7.5%) and various content of both fly ash and nanosilica. Polypropylene fibres were added to all mixture in order to prevent the spalling effect due to the exposure to high temperatures, and the water/binder ratios were also constant (0.4). Steel moulds with dimensions of 40 x 40 x 120 mm were employed for casting. All specimens with fly ash were left for 2 days in the moulds, while the rest were removed after 1 day and all of them were submerged in lime-saturated water for 3, 7 and 28 days for curing purposes. The samples were exposed to 400 °C and 700°C for 2 hours using the lab furnace and then were left for 2 days to slowly cool at the room temperature. Both compressive and flexural strength tests were applied to the cooled specimens. It was found that at the exposure of 400 °C the specimens with Nano Silica has a greater increase in compressive strength than the ones without nanosilica. This is because of increasing the hydration process (as a result of heating) that produce more calcium silicate hydrate which, in turn, shall increase the nanosilica reactivity, hence improving the strength. In the case of flexural strength test, however, the samples have exhibited various responses. For instance, the samples with fly ash have shown an enhancement in flexural strength at 400 °C, while the samples with both nanosilica and fly ash has an increase of flexural strength during the early curing periods only, and finally, the ones with nanosilica only has a decrease. This diversity in behaviour is because flexural strength is more susceptible to the appearance micro-cracks (due to the accumulation of vapour pressure), which decreased the samples cross-sectional area, thus influencing the flexural strength. Furthermore, tensile stress has expanded the cracks. In other words, temperatures have a more devastating impact on flexural strength and compressive strength. As for 700 °C exposure, both flexural and compressive strengths has significantly dropped which is due to the redundant accumulating vapour pressure, which consequently produce huge cracks in samples. Moreover, the binder material in the cement paste has dehydrated which has caused a decrease in strength. However, more residual strength is recorded in the specimens with nanosilica. Therefore, it is concluded that applying nanosilica and fly ash can produce mortars with equivalent strength even after exposure to 700 °C heat.

Nadeem et al. (2013) [15] has inspected the performance of cement mortar under high temperatures using adding materials such as metakaolin and fly ash. 7 mortar mixtures were prepared for this investigation. The first mixture with no additives is called the control mix. The rest, on the other hand, have different percentage of metakaolin (5%, 10% and 15%) and fly ash (20 %, 40% and 60%). After 24 hour from casting, the samples were demoulded and submerged in a water tank for 28 days for curing. Thereafter, they were placed in a temperature controlled room (27 °C) and with humidity of 65% for 5 months. The samples were subjected to elevated temperatures from 200°C to 800°C. It was found that all samples has suffered a major decrease in compressive strength after 400°C. However, the ones with 20 % fly ash content has showed better performance than the rest.

Abd El Aziz et al. (2013) [16] have investigated the coupled effect of elevated temperatures and cooling conditions on the characteristics of the Ground Clay Brick (GCB) Mortar. 10 different mixtures were prepared for testing. The first three mixtures have no additive materials are are referred to as the control samples. The rest have the GCB used as partial (33% and 66%) and full replacement of sand. Furthermore, all samples have different cement content (350, 400, 450 kg/m$^3$). The samples were poured in 50 m$^3$ cubes, and demoulded after 24 hours. After 90 days of curing, they were kept in laboratory atmospheric conditions for six months in order to obtain a composition with a steady state. Thereafter the samples were exposed to 700°C for 3 hours and then were cooled using three different cooling methods: water cooling, air cooling, and switched off furnace cooling. It was shown that the samples with higher cement content has demonstrated better values of compressive strength before heating. After heating, however, the strength decrease with cement content higher than 400 kg/m$^3$. Which is due to the reduced permeability, which makes it more susceptive to explosive spalling under fire condition as a result of accumulated pore pressure in the mortar. Furthermore, a noticeable decrease in compressive strength was observed in the air-cooled samples when compared with the water-cooled and furnace cooled. This because of the long-term exposure to atmospheric conditions that results in carbonation process of CaO. Finally, the sample with GCB as full replacement has achieved highest compressive strength before and after heating. This because of the pozzolanic reaction of the GCB with the liberated lime, thus producing extra amounts of CSH, CAH and CASH hydrates. These are deposited within the pore system and lead to the formation of a strong internal structure.

Heikal et al. (2014) [17] have researched the influence of adding nanosilica, slag, and superplasticizer on the structural characteristics of cement mortars. 16 mortar mixes were used for this objective. The first mix has no additives and is referred to as the control specimen. The rest have different content of nanosilica (0-6%), slag (30-60%), and superplasticizer (0-1%). 1 inch cubic moulds were used to cast the samples and were placed in a humidity chamber for 1 day. Thereafter, they were cured by submerging them in water for 1, 3, 7, 28, and 90 days. After 24 hours drying (at 105°C), the cubes were heated in the lab furnace at 200, 450, 600, 800, and 1000°C for 3 hours, then were air-cooled in the room temperature. It was observed that the samples with 30-60% slag content and, 4% nanosilica have higher thermal resistance than other ones, which can be attributed to the increasing consumption rate of portlandite.

Ghazy et al. (2015) [18] have inspect the impact of employing nano-metakaolin, fly ash, and silica fume on the residual mechanical and physical properties of cement mortars. Total of 7 mortar mixes were prepared for this experiment. One mixture with no additives was considered the control mixture, the rest has different content of nano-metakaolin (5-10%), fly ash (5-10%), and silica fume (5-10%). The 50 mm$^3$ cubes were used to cast the mixtures. The specimens placed in water for 28 days for curing and afterwards were dried in the lab oven at 105 °C for 24 hours. Thereafter, the samples were subjected to elevated temperatures of 200°C, 400°C, 600°C, 800°C where each temperature has been maintained for 2 hours. The samples were tested for compressive strength at each temperature using a machine of 300 kN capacity. It was found that applying replacement of both nano-metakaolin and silica fume has accomplished the best improvement in compressive strength (by approximately 40.33%) at the lab temperature. However, mixtures with nano-metakaolin and fly ash has demonstrated the best performance when exposed to high temperatures.

Maheswaran et al. (2015) [19] have investigated the influence of elevated temperatures on the strength properties of cement mortars combinations using additive materials such as lime sludge, silica fume, nanosilica. Five mortars mixes were prepared for this purpose. The first sample (control sample) has no additive materials. The remaining four had the cement been replaced by lime sludge by 20%, and silica fume was added to two samples (3 and 6 % from the cement weight), while nanosilica was added to the other two (1.5 and 3 % from the cement weight). In addition, superplasticizer was added to the last four to maintain uniform workability during the flow test. The samples were cast in 50 $mm^3$ cubic moulds. After 24 hours, they were removed from moulds and were placed in water for curing for 3, 7, and 28 days. Laboratory oven was used to heat the cured specimens by up to 800 °C and they were left to cool at the oven to room temperature. It was found from the results that replacing cement with lime sludge and silica fume can remarkably enhance the compressive strength during the heating process until 500°C. Beyond that, however, the decompositions of calcium silicate hydrate occur which considerably weaken the pore structure, eventually causing spalling. As for the mortars with lime sludge and nanosilica. Although they have less compressive strength during the test, they don't suffer spalling even after 500°C. This is because of their improved particle packing density and because of the nanosilica pore-filing effect.

Horszczaruk et al., (2017) [20] have investigated the effect on nanosilica and heavyweight aggregates on the elevated temperature performance of cement mortars. 18 mortar specimens with different mixture were employed in this study. Three aggregate types (barite, quartz, and magnetite) with fineness less than 2 mm were used, and the nanosilica content was between 0 and 5%. Furthermore, superplasticizer was used for samples with barite aggregate. The samples were poured into 4 x 4 x 12 cm. After the curing period (28 days) and drying (constant 105°C), the samples were exposed to elevated temperatures from 200 to 800°C. It was found that the type of aggregate greatly affects the fire resistance behaviour of cement mortars. For example, samples with magnetite aggregate have the highest thermal stability. Barite aggregate samples, on the other hand, have demonstrated a thermal spalling due to the low conductivity of barite. Finally, the samples with quartz aggregate have displayed proportionally fine mechanical characteristics until 400°C where it suffered a remarkable decrease in flexural strength and mass losses. Furthermore, nanosilica can optimize fire-resistance performance due to the chemical reaction with lime producing an extra sum of Calcium Silicate Hydrate, which improving the cement microstructure. Consequently, preventing the spreading of cracks at high temperatures.

Abdulhussein et al. (2018) [21] have researched the effect of adding superplasticizer and crushed bricks on the mechanical characteristics of cement mortars under elevated temperatures. 7 specimens with different mixtures were applied for this research. The first specimen consisted of cement and sand only is considered the control model. Three samples have the sand content replaced by crushed brick by 25, 50, and 100%, and the last three in addition to crushed bricks have superplasticizer added by 1, 2 and 4% from cement weight. The specimens were cast in standard moulds for 24 hours. Following 28 days curing period, they were exposed to various heats (100-700°C). Thereafter, half of the specimens were slowly cooled by letting them at the oven temperature. While the rest were rapidly cooled by saturating them in water. It was seen from the result that the compressive and flexural strengths for all mixtures increase as the heat rise. However, the strengths for the air-cooled the samples have started to drop beyond 200°C, and the water-cooled ones started to drop beyond 100°C. Also, samples with crushed bricks have lower fire resistance (especially the ones with 100 % crushed bricks content) than the ones without, but with the addition of superplasticizer, it has achieved the highest fire resistance.

Sazzad et al. (2020) [22] have inspected the influence of steel fibres on the compressive strength of cement mortars under high temperatures. 4 types of specimens were prepared for the experimental investigation. The 1 specimen has no additives and were referred to as the control specimen. The remaining three have steel fibre added to the mix by 2%, 4%, and 6% respectively. The specimens were casted in 25 $m^3$ cubic moulds. Half of the cubes were cured for 3 days and the other half was cured for 7 days. After drying the specimens at the room temperature, they were exposed to elevated temperatures of 250°C, 450°C, and 600°C. The cubes were divided into three groups: the first were tested for compressive strength immediately after reaching the required temperature, the second were tested after 30 minutes cooling, and the last were tested after 60 minutes cooling. In general, it was demonstrated that the compressive strength of the cement mortars increases with the increase of cooling time. However, the samples with steel fibres has higher strength than the control sample regardless of the cooling time. Also, cement mortars with 4% steel fibre has demonstrated the best results, however, the compressive strength decreases after 450°C heat for all samples regardless of the percentage of steel fibre. Figure (1) displays the obtained results.

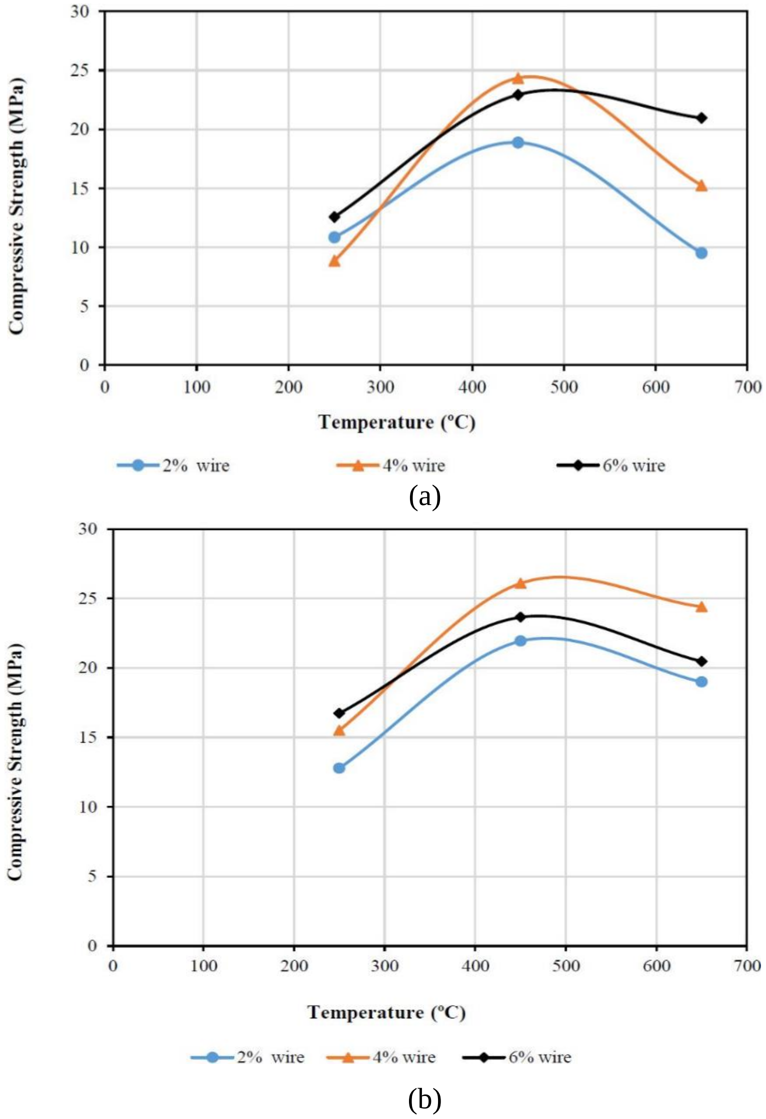



**Figure (1**) Effect of steel fibres on the compressive strength of cement mortar under elevated temperatures: (a) after 3 days of curing (b) after 7 days of curing.

## 3. Summary

This paper has summarized the studies since 2005 regarding the structural performance of cement mortar under elevated temperatures, and a chronological narrative manner was used to examine and express them. It can be seen that researchers have focused on improving the fire-resistance performance of cement mortars using additive materials. 7 researches have considered employing fly ash, while 5 have investigated the effect of silica fume, nanosilica and superplasticizer, 4 have assessed the influence of metakaolin and slag , and 3 has inspected the impact of pumice. Finally, 2 studies have inspected influence of crushed bricks, while natural pozzolan and steel fibre were suggested by 1 study for each. see Figure (2).

As for the cooling method, it can be shown that only 3 investigations have applied water-cooling (W-cooling) for the specimens, and only 1 study has considered furnace-cooling (F-cooling). As for the rest, air-cooling (A-cooling) was employed (see Figure 3a). Also, in the manner of the types of conducted tests, 18 researches have inspected the influence of compressive strength (Comp st.), flexural strength (Flex St.) test, on the other hand, was applied by 6. And finally, only one investigation has inspected the fractural energy (Fr en.) of cement mortars. see Figure (3b).

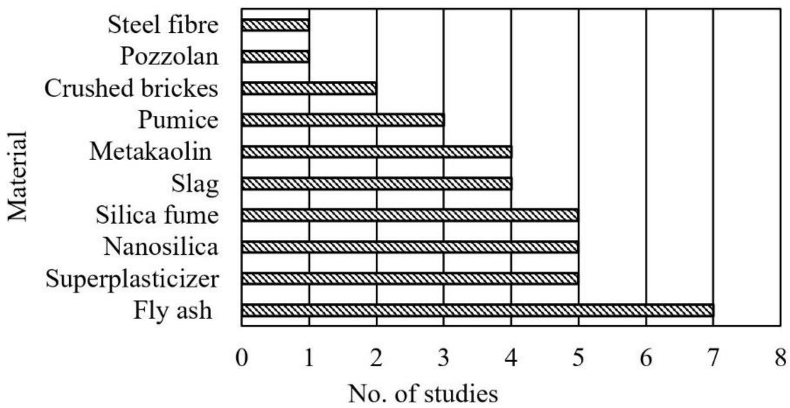
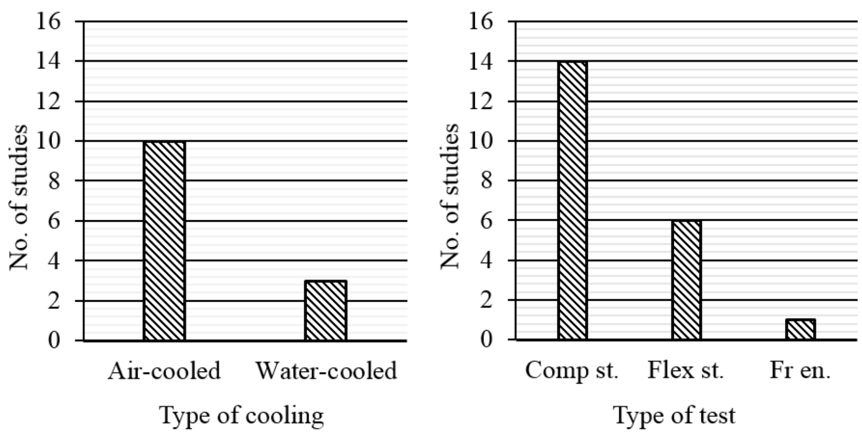



**Figure (2)** Number of studies conducted on cement mortars depending on the type of additives**.**




(a) (b)

**Figure (3)** Number of studies conducted on cement mortars depending on:
(a) type of cooling, (b) type of test.

## 4. Conclusion

In this paper, a literature review was stated and reported regarding the present knowledge on the fire-resistance performance of cement mortars. Each research has followed a certain line of investigation, however various conclusions can be drawn when comparing the studies with each other.

1. Exposing cement mortars to high temperatures (which is similar to the fire situation), has a negative impact on their mechanical properties, especially the ones without additives.
2. Some additive materials (fly ash for example) cannot make much change in the thermal-resistance when it is used alone. However, when it was combined with other materials (pumice or pozzolan), it can greatly enhance performance.
3. Compressive strength of cement mortars rises with increasing the cooling time.
4. Flexural strength is more vulnerable to heat when compared to compressive strength.
5. Water-cooled mortars is more sensitive to heat than air-cooled ones.
6. Studies have mostly focused on the physical properties of cement mortar under elevated temperatures. Therefore, chemical characteristics should also be considered in future studies.

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