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# Effects of MgO-based expansive agent on the characteristics of expansive concrete †

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**Abstract:** Expansive concrete are used to reduce cracking caused by drying shrinkage in concrete structures such as slabs, beams, columns and pavement constructions. Although CaO and Sulphoaluminate based expansive agent have been used for decades, MgO-based expansive agents have demonstrated superior performance since 1970, especially for concrete dam structures. It has been proven that compensating shrinkage with MgO expansion efficiently prevents thermal cracking of mass concrete, reduces the expense of temperature control systems, and speeds up the construction process. This paper reviews indicates several parameters such as reactivity, thickness of water film, curing condition, additive ratio, and calcination condition that affects the expansibility, strength, soundness, durability, flowability, pore structures, crystal size, and hydration activity. The review indicates that the expansion characteristics of MgO may be designed flexibly by altering the calcination conditions (calcining temperature and residence time), maintaining a certain curing temperature and tweaking its microstructure.

**Keywords:** expansive agent; MgO-based expansive agent; curing conditions; calcining temperature.

## 1. Introduction

Buildings, bridges, tunnels, dams, and highways are examples of civil infrastructure that may be damaged in many ways across the world. Cracks are one of the types of damages that can severely reduce the service life of reinforced concrete structural parts [1]. Concrete constructions can crack as a result of structural design flaws, poor construction techniques, or unfavourable interactions with the environment. Concrete fractures might start off as tiny microcracks that link throughout the microstructure, eventually producing significant internal damage before becoming evident on the outer surfaces [2]. One of the most common causes of cracking is shrinkage of cement-based materials, which has a detrimental impact on building durability [3]. It often generates cracks which are produced by heat contraction or drying shrinkage when exposed to climatic conditions and restricted internally or externally [4]. To cater the shrinkage cracking of concrete, for more than 50 years, researchers and practitioners have investigated and applied expansive hydraulic cements including expansive agents which accommodates the shrinkage characteristics of concrete and further enhances strength and durability [4]. The three common expansive agents are based on calcium sulfoaluminate, calcium oxide (CaO), and magnesium oxide (MgO). When it comes to preparing shrinkage-compensating concrete, sulfoaluminate-type and calcium oxide-type expansive agents are the most often employed expansive agents. Some drawbacks, such as poor temperature stability and an unpredictable hydration pace, have limited their application. A potential expansive agent, MgO-based expansive agent, has recently been discovered. It is typically generated by calcining magnesite, and the reactivity of expansive agent may be readily regulated by the calcining conditions used to produce it. Years of study have resulted in the successful use of MgO-type expansive agents in a variety of applications. As a result of the chemically stable hydration products, the relatively low water requirement for hydration, designable expansion property, and lack of obvious shrinkage in the late age, MgO-based expansive agents have been used in various parts of more than 60 dams in China. The poor thermal conductivity of mass concrete allows for considerable temperature increases caused by the heat of cement hydration. This produces significant thermal shrinkage throughout the cooling stage, which is a key contributing factor to shrinkage cracking at later ages. Conventional methods of preventing the thermal shrinkage cracking in mass concrete, such as using cement with low hydration heat, mixing with a high volume of supplementary cementitious materials as cement replacements, pre-cooling the raw materials and/or post-cooling the concrete by embedding cooling pipes, are widely used to reduce the maximum temperature rise and, consequently, the thermal shrinkage cracking. Nonetheless, some of these conventional processes are expensive, and because to the extended duration of the process, thermal shrinkage of super big mass concrete, such as dam concrete, cannot always be fully avoided.

Engineers have been looking for an expansive agent that can provide the necessary expansion to compensate for the particular shrinkage of concrete. MgO-based expansive agent surpasses conventional expansion agents in terms of designable expansion property, which is very important. As a result, this paper will review on the factors that effects the characteristics of an expansive concrete that contains MgO as the expansive agent. The characteristics are going to be defined by assessing the expansibility, durability, volume deformation, thermal cracking and so on.

## 2. MgO-based expansive agent: a brief history and application

It all started in 1884, where periclase (magnesia) had been used to develop expansive behavior in concrete. But due to delayed excessive expansion and hydration process, some bridges in France and City Hall of Kassel in Germany failed. As a result, the usage of magnesia had been limited to 5% all over the world and 6% in America. Later in 1970, a concrete dam named as Baishan dam had been constructed using 5% of MgO as an expansive agent. The results came out surprisingly good whereas there are no cracks developed in the concrete foundation although there was no measures were taken on temperature control. This success dragged researchers attention on developing MgO-based expansive agents and thus, several dams were constructed in China using the same expansive cement. Dam construction technology has demonstrated that delayed micro-expansion of MgO concrete can be used to allow the concrete to produce appropriate pre-compressive stress, reducing or balancing the tensile stress generated during concrete temperature drop which improves the crack-resisting performance of concrete, and fundamentally resolves the crack control problem. Longer blocks, thicker layers, non-installed construction joints from the left to the right bank, and all-weather continuous concrete placement may also be achieved, as well as a reduction in construction time and project cost. This is a major advancement in concrete dam building technique [5].

MgO offers numerous benefits over typical expansive cements or expansive additives such sulfoaluminate, aluminate clinker, or CaO-based expansive additives, which are currently widely utilised in Japan, the United States, and China [6]. This comprehends $Mg(OH)_2$, its chemically stable hydration product, relatively low water requirement for the hydration of MgO, and specifically its designable expansion properties [7]. The benefits of MgO in correcting concrete shrinkage and improving concrete durability have been demonstrated in both experimental and industrial applications.

Coming forward to 2021, demand of dam for producing hydropower, reservoir of fresh water etc. is enlarging day by day. As a result more and more large concrete dams with height over 200m will be constructed worldwide, which provides a potentially huge market for the application of MgO concrete. The mix proportions of MgO concrete must be well-designed, and the expansion must be carefully controlled to meet the shrinkage of the concrete. Thus, for dam concrete, temperature rise, thermal stress, and concrete shrinkage in various structural elements of the dam must first be anticipated using simulation calculations, after which the optimum expansion process of MgO concrete required for complete shrinkage compensation can be projected.

## 3. Factors influencing the characteristics of expansive concrete

MgO-based expansive agents manipulate the characteristics of expansive concrete in various ways. In this paper, the factors are categorized into five different areas in which several researchers have conducted experiment and concluded in some decisions.

**Table 1.** Factors effecting the characteristics of expansive concrete

| Factors | Authors |
| --- | --- |
| Hydration Process | **[8-11]** |
| Calcining Temperature | **[1], [12-16]** |
| Curing Conditions | **[11], [17-19]** |
| Autogeneous Volume Deformation | **[20-22]** |
| Mechanical and Self-healing Properties | **[7], [23]** |

### *3.1. Hydration process*

Desiccation, chemical reactivity, and temperature change can produce volumetric shrinkage of cementitious materials, which can create tensile stress and cracking of concrete that is confined in a structure [8]. Expansive agents were added which reacts with water and cement in order to develop volume expansion and decrease concrete shrinkage. Because of its controlled reactivity speed and expansive capacity, as well as its extremely stable hydration product, MgO is an excellent expansive agent. Furthermore, MgO's hydration product is just $Mg(OH)_2$, a very simple and stable crystal that does not dehydrate until temperatures reach 350˚C, making MgO a safe expanding agent. Whereas other expansive agent such as Sulphoaluminate-based ones start to dehydrate from 70˚C [9]. Lu et al.[10] experimented that the conductivity of MgO-based expansive agent at 50˚C is double as of at 25˚C, proving that curing temperature influences the hydration characteristics of Mgo-based expansive agent in concrete. Supporting it, Mo et al.[11] also found out that if the type of EA and curing age is kept constant, the temperature is proportional to the hydration rate.

### *3.2. Calcination temperature*

MgO particles may be employed as expanding agents to compensate for thermal shrinkage and therefore avoid cracks in mass concrete caused by thermal stresses [12]. MgO is typically produced by calcining magnesite at a temperature ranging from 900 °C to 1450 °C which creates difference in reactivity and expansion rate. Mehta et al. [13] claimed that properly calcined (at temperatures between 900 and 950 °C) and sized (300–1180 m). Sherir et al.[1] found that when

MgO particles were burned at 900°C, they produced a more reactive MgO-type expanding agent than when they were burned at 1300°C. Moreover, Mo et al.[14] investigated that higher calcination temperatures and longer residence times promote MgO grain development, resulting in a reduction in inner pore volume and specific surface area, and consequently a reduction in hydration activity. Early hydration causes shrinkage cracking at the late age. Magnesium oxide crystals become increasingly perfect as the calcining temperature rises, lowering reaction activity [15]. Chen et al.[16] has kept the residence time constant at 1 hour, and found out that MgO-based expansive agents calcined at 900°C reacted with water quickly and accomplished 85% of hydration within 2 days. When the temperature was raised to 1100°C, it took 30 days to hydrate 83% and only 10% after increasing the temperature to 1300°C. On the basis of the foregoing, the adjustment of magnesite calcination temperature and residency duration could be achieved by various types of expansive agents designed to compensate for dam concrete needs.

### *3.3 Curing conditions*

Li et al.[17] studied the temperature history of MgO-based expansive agent, finding it very important in regards to hydration and expansive characteristics. The standard water curing occurs in between 20°C to 80°C. Fang & Yongchao[18] experimented the effects by keeping the curing duration to 90 days with 10% of MgO-based expansive agent mixed with the cement. He found out that the range of 20°C-40°C has very little effect on the expansion but the range of 40°C to 80°C increases the expansion rate exponentially as the temperature increases. Findings of Mo et al.[11] also shows the increment in expansion rate as the temperature raises, observed after 360 days. Because the expansion of cement paste is determined by the conflicting effects of the expansive stress generated by MgO hydration and the resistance of the hydrated cement matrix to expansion, the influence of curing temperature on cement paste expansions may be attributed to the increment of the hydration of MgO by increasing the temperature. The MgO hydrated quicker and generated more hydration products at a higher curing temperature, inducing a faster and bigger expansion, especially at an early age. Qian et al.[19] investigated the mechanical effects of different curing temperature. He found that at later ages, 20°C - 60°C curing temperature results in decrement of compressive strength while cured below 20°C provides better compressive strength values. Two well-known processes have been proposed to explain the crossover effect observed in MgO-based expansive agents. The first, and probably most important, is that the quick hydration rate at a younger age would result in inhomogeneous and porous microstructures, decreasing the final strength of cementitious materials. The second point to note is that the response rate is significantly quicker than the diffusion rate. As a result, the majority of the hydration products remain near the unhydrated grains. As a result, these densely deposited hydration products will form barriers to ionic diffusion, limiting hydration rate and compressive strength increase at later ages.

### *3.4 Autogenous Volume Deformation*

Autogenous volume deformation of the concrete is an essential index often employed in building design and control design of mass concrete projects when calculating a temperature stress. Experiment conducted by Gao et al.[20] shows that when the concrete specimens had been cured for 180 days, the autogenous volume expansion of conventional concrete with MgO-based expansive substance increased with the amount of MgO and curing age, and tended to remain constant. The shrinkages of concrete were not found when the MgO-based expansive agent were blended in the concrete, which were compensated by the hydration of the expansive materials in concrete. Nguyen et al.[21] researched on the effect of different curing temperature and percentage of MgO content on autogenous volume deformation. He found that the hydration of the expanded elements used in concrete has compensated for concrete shrinkage whereas MgO mixed concrete tends to expand fast at a young age, but remains constant at older ages. Moreover, Chen et al.[22] studied on autoclave expansion deformation and found that with the rise of magnesium oxide mixture concentration, the autoclave expansion rate for cement-based materials is increasing. This applies regardless of the kind or the size of the material. When the amount of combined magnesium oxide reaches a particular threshold, the autoclave expansion of the specimen increases significantly.

*3.5 Mechanical and Self-healing Properties*

Proper expansion of concrete with appropriate amount of MgO-based expansive agent addition can enhance mechanical characteristics. Mo et al.[7] stated that the effect of MgO-based expansive agent on the mechanical performance or durability of concrete is determined by the impact of expansion on the microstructure. The expansion helps to improve the microstructure of concrete by reducing pore size and total pore volumes, for example. It has the potential to improve both the mechanical strength and the durability of concrete. Qureshi et al.[23] also found out that stiffness improvements were found increasing with the addition of higher proportions of MgO. While treated in an immersed state for self-healing, samples were discovered to have expanded. The crack points might get closer as a result of this expansion, which speeds up the self-healing mechanisms. Stronger amounts of expansive MgO in the samples revealed higher expansive characteristics during healing, resulting in faster healing of larger cracks. Overall, the addition of MgO enhanced the durability by increasing crack sealing and strength recovery (load recovery and stiffness improvement). However, the quantity of expanding MgO that causes the best self-healing performance has a limit.

## 4. Conclusion

MgO-based expansive agent have come far from where it started and now is being used industrially as a reliable expansive agent. The volume stability, mechanical strength, and durability of MgO concrete are all directly connected to the raw ingredients, mix percentage, curing conditions, calcination temperature etc. The effect of MgO's expansion on concrete performance is determined by its influence on the microstructure of the concrete. Appropriate expansion helps to densify concrete and improves its performance, whereas excessive expansion can damage the microstructure of concrete and degrade its performance. However, the manufacture of MgO with adequate properties on a large industrial scale, precise control of the expansion process of concrete containing the appropriate type and addition content, and evaluation of MgO concrete soundness are some of the challenges faced in the application of MgO concrete in constructing super large concrete dams. The expansion of MgO concrete must be carefully planned and precisely regulated, taking into consideration the impacts of temperature, restraint conditions in various structural components, and the thermal stress field in the dam structure. Furthermore, simulation technology for predicting MgO concrete temperature, thermal deformation, and expansion is critical and should be enhanced.

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