PERFORMANCE PARAMETER ANALYSIS OF MAGNESIABASED CEMENT PRODUCTS – A REVIEW

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Abstract. Magnesium oxide (MgO) based cements finds its way active in current researches where diverserange of applications and characteristics such as production process, reactivity and physical properties are essentially focus with the perception of individual expansion objectives. In general, relativity between distinctive MgO characteristics is examined in conjunction with the impact of MgO embodiment on the resources of cementitious materials is further considered. MgO is a key to develop the construction industry thereby mechanical strength and durability performance of cement paste, adhesive and concrete composites impose of MgO needs to be explored. Subsequently, this research paper explicitly defines the investigation of MgO cement composites in terms of compressive and flexural behavior, toughness, tensile and durability performances, flexibility, water susceptibility, porosity, carbonation, chloride ion diffusion, shrinkage and degree of hydration. In this regard, to application of magnesia-based cement products is influenced by various factors such as raw material, composition, performance. The review provides a detailed information of current research available related to magnesia-based cement products based on its properties.

Keywords: Materials, Magnesium oxide, Chemical properties, Physical properties, Environmental applications, Construction products.

1. Introduction
The description “everything decrepit is brand-new again” is absolutely suitable to the present condition of cements based on magnesia (MgO). The overall materials construction industries are significantly based on quite expanded range of materials relevant for provincial conditions and standard applications as highlighted by M. Aminul Haque & Bing Chen(2019). On the other hand, mean of the 20th century has become relatively a monoculture form on the utilized of Portland cement (PC) inclusive of alternative materials essentially confined. The emerging progress of magnesium phosphate cement was discussed towards physio-mechanical behaviour on different applications[1]. The utilization and resource of magnesium phosphate cement was pointed by the consideration include bio material, cracks, waste management and fibre reinforced mortar. The strengthen results were designed based on reinforcement and combination of materials. Likewise, the MPC ensures regular usable products such as biomedical application and other usages. The acoustic
and thermal insulation are likely to frame over light weight MPC mortar of interior walls to improve and maintain the strength at nominal cost. Subsequently, bio ceramics facilitates through MPC in the field of biomedical engineering applications as a result this technique seems to be high scope for bone and root canal materials.

In the 21st century, the advancement for increasing environmental sustainability in the construction industry necessitates further exploration where the overall industry is retrieving large-scale concern in materials which is identified for decades and significance rate [2]. This facilitates to the rediscover of an extensive volume of information that has been precedent to imply. The key direction of this review is to deliver the information in the context of modern usage of MgO-based cements incorporated with outcomes achieved more in recent past as these materials have become rear into focus and utilization [3]. In particular, the outline of information highlights the rate of high-quality chemical and scientific data in developing and identifying the materials.

In general, the prevailing structure of cement across the globe is Portland Cement (PC) with approximately 4.6 billion tonnes produced every year as suggested by Meng Miao et al [4]. Further, it is reported that the production process of the cement liberates enormous amount of carbon dioxide and other greenhouse gases into the air causing harmful effects on the environment.

Exhaustion timber framework from development sites was enhance fibre to produce wood magnesium oxychloride cement as discussed by Pingping He et al [5]. The consequent result originates that wood based MOC composites produced with greater content of wood fibre to address minimal thermal conductivity, greater flexural strength, superior residual flexural strength later exposure to high temperature and concentration of water which in turn exposes improved noise reduction.

Ferdous, W et al has attempted the utilization of cement, during initial phase the material provides high internal pH around 12−13 naturally in addition that holds rigid mild steel emphasize in passive phase [6]. Hence it attempt degree of stability from corrosive activity of destructive agents such as chlorides (Cl⁻). This in turn necessitates replacement mechanism towards renewable concrete through MgO development [7]. Cements with large-scale MgO content promote significant demand in the last decade which is primarily due to the expanding concern over climate changes with the objective and need to reduce the CO₂ discharges combined with the manufacturing of conventional Portland cements. Xing Sainan et al suggested the corrosion behavior of A3 steel generally termed as magnesium sulfate. In a row, to analyze the overall ratio of raw materials like magnesium oxychloride cement and Portland cement ensure to prevent reinforcement from long-term corrosion effect [8].

2. Carbonation
Moreover, the carbonation of MgO can be illustrated as construction of magnesite from MgO over the consumption of carbon dioxide (CO₂). As a part of operation, the performance of MgO offers calcinations and reactivity which in turn minimize the thermal shrinkage, reduction of concrete cost along with high-priced cooling measures thereby stimulate development process acceleration through frequently casting concrete without demand of cold joints [9]. Moreover, the prime objective for improvement and adequate of MgO based cements fitted with an environmental nature with relevance to real time conditions. The diminished temperature is appropriate for construction of MgO compared to the alteration of CaCO₃ into traditional Portland cement (TPC) here accumulation of energy is associated with reduced temperature that paves way for anticipate MgO based cement as central suggesting for environmentally friendly cement manufacture in future [10]. Similarly, the ability of MgO is to absorb CO₂ from the atmospheric surrounding to form variety of carbonates and hydroxy carbonates which is termed as carbon neutral cement (CNC) [11]. Also, this could absorb large amount
of CO2 over its lifetime as that emitted at the time of manufacture. These two complementary aspects compel to recent grow in interest for both academic and industrial based researchers in the field of MgO based cements.

Ruan, S., & Unluer, C. (2017) has been carried out regarding significant influence of mix design on the carbonation and hydration of reactive MgO cement were studied under varying water and cement contents. Reactive magnesia cement specimens were achieved better strength than Portland cement samples. The MgO specimens were accompanied with amount and morphology of carbonates and decrease in porosity. The lower water content was led to higher strength due to faster CO diffusion and lower porosity [12].

Dung, N. T., & Unluer, C. (2017) has presented the microstructural and mechanical behaviour to investigate the development of reactive MgO concrete under various CO2 concentrations. The reaction mechanism were accompanied with improved morphologies which is translated to higher strength. The 5 - 20% of CO2 were induced the carbonate phase formation with superior mechanical properties. Higher concentration of CO2 was attained rapid strength gain and lower concentration of CO2 was deliver the similar performance with sufficient time [13]. The carbonation and low hydration of MgO limits its carbonation and strength gain. The carbonation were enabled by a peak amount of brucite for carbonation. The higher usage of MgO were enhanced the CO sequestration ability of brucite and increased the brucite available for carbonation [14]. Finally, the detailed literature review we have discussed based on the types of magnesia-based cements, performance parameters of the product under study. The detailed discussion is important to understand the research progress for the magnesia-based cements. This will eventually pave way to further research into the magnesia-based cements and eventually all the shortcomings will be addressed, which can lead to commercialization of the magnesia-based cements.

3. Types of Magnesia based cements
Chenggong Chang et al (2018) have addressed magnesium oxychloride cement was formulated from magnesium slag along with hydrochloric acid from the product of Li2CO3 from salt lakes. The different composition of magnesium slag calcined at different temperatures were analyzed by hydration method and XRD. Consequently, the preparation of MOC specimens were fabricated with calcined magnesium slag and different concentration of hydrochloric acid. Hence, the observed results pointed that magnesium slag activity were decreased with increasing temperature of calcination. The MOC specimens were attained high strength due to high concentration of hydrochloric acid. Therefore, author has determined the possibility to prepare the MOC with magnesium oxide and hydrochloric acid reaction [15]. The author has come up with the magnesium carbonate, phosphate, oxy salt and silicate hydrate cements. This research pointed the MgO based cements were placed for the replacement of Portland cement in steel reinforced concretes for advanced engineering applications, despite the potential for CO emissions. In this stage, the durability of these cements, materials and formulations were investigated periodically. Therefore, MgO based cements seems to be eco-friendly for the civil engineering applications.

Magnesia based cements prepared by using MgO with 60% of the CaO composition of PC. The different configuration of MgO and CaO were observed. Comparison of (MgO, CaO) represents the massive differences in phase of formation and construction was determined. Subsequently, different methodologies are highly needed for the development of MgO based cements. The acid based cements prepared towards the reaction between acid phosphates and MgO. In relevance to higher energy consumption magnesium oxide is prepared through the calcination of magnesium deposits or magnesite.

The MgO preparation over dry route production is need to crush the magnesite before calcination. The MgCO3 was collected from bearing rocks and pre-treated process takes place due to Fe2O3 and SiO2.

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impurities. The wet route production of MgO is complex and its needs the precipitation of Mg (OH) solution rich in Mg from mining brines or sea water. Thus, the MgO products are arranged based on reactivity and calcination temperature.

In a row, reactive magnesia and magnesium carbonate cements are developed in large scale production due to the properties of reduction of CO₂ or CO₂-negative cements.

\[
\begin{align*}
\text{MgO} + \text{CO}_2 & \rightarrow \text{MgCO}_3 \\
\text{MgO} + \text{H}_2\text{OMg} & \rightarrow \text{(OH)}_2
\end{align*}
\]

The reactive MgO is an expensive additive and quite distinct in cement binders. The temperature increases in excess of 50°C extending towards hardened of concrete. The regulatory standards provide restrictions to MgO based cements due to long term dimensional instability. The sufficient calcination and level of fineness ensure expansion as to cause dimensional stability issues [16]. Reactive magnesia based cements are not demonstrated in ambient condition due to that durability of long-term of prepared phases was not ensured. Therefore, the control of internal humidity and CO enhancements to form binding carbonate phases that also needed to be examining for long term durability. MgO cements such carbon negative cements has been produced potentially from magnesium silicate sources and the replacement of PC in unreinforced block production and other factory produced units.

4. Issues in Magnesia based Products
Properties of magnesium phosphate cement (MPC) were studied by Park et al [17]. The specimens were fabricated with magnesia and added the potassium dihydrogen phosphate (K₂HPO₄) to activate hydration process. The flexural and tensile strengths were investigated to assess the characteristics in large scale. An increase in the M/P ratio resulted in an increase in the porosity. In particular, the entrained air void mostly attempts to employ the pore range of the magnesium phosphate cement. Moreover, the setting time was significantly reduced the purity of magnesia with increasing number of compressive durability, bond stability to old substrate and framework time [18].

T. Goncalves et al. (2019) has suggested two different reactive MgO samples were analyzed as partial replacements of cement (at 10%, 15%, and 20%, by weight) in the mortars production [19]. Furthermore, differential thermal analysis, Thermogravimetric analysis, energy dispersive X-ray analysis, powder X-ray diffraction analysis of cement, MgO samples and observed resulting of mortars were analyzed respectively. The fabricated specimens has evaluated based on their mechanical characteristics and related performance. Hence, MgO elements effectively exhibit reduced shrinkage induced cracking thereby improving the materials and structural related performances.

Zhang et al. (2018) has highlighted a magnesium oxide carbonization block to examine its type of environmental protection block based on activated magnesium oxide cementation technology. The CO₂ carbonation mechanism allows the reactive magnesia which in turn acknowledges the necessary magnesium carbonate to increase the durability and compressive strength of the block [20]. The research has presented maximum compressive strength, higher amount of active magnesium oxide further it is proven that compressive strength of the fabricated block reaches or even exceeds 80% and it may reaches the maximum compressive strength about 2–3 times of the ordinary cement block.

Zhongcheng Ma (2020) et al have addressed the quantitative analysis regulate to determine the periclase standard in high magnesia Portland cement by Thermogravimetric and chemical analysis[3]. Despite the advanced becomes highly essential platform to evaluate the properties towards distinctive applications according to the requirements. The auto clave test ensure the hydration of periclase and the Thermogravimetric analysis to avoid the intrusion of fused MgO on cement as well as the chemical analysis can be easily eliminate the significance of Ca(OH) and Mg(OH) on the result of periclase.
content in cement.

Zimina and Nutskova (2019) has pointed the magnesia materials which improve cementing quality through complete bond and contact at cement casing and rock cement boundaries [21]. Furthermore, magnesia cement materials comprise of high expanding capacity which in turn ensure the annulus integrity space towards the replacement of drilling mud with cement. Therefore, MgO with additives were influenced on strength of cement with more distinct volatile compositions of additives like silica fume which refers to sterilization of ore-thermal forge at metallurgical activities. The expensive additive of MgO be composed of cement to compensate for the mass concrete over thermal shrinkage. Subsequently, the MgO is identified to prevent the thermal cracking of concrete effectively which in turn minimize the overall evaluation of temperature control. The particle content acquire greater influence of its hydration reactivity and its relevant expansion. Therefore, microstructure of MgO along with hydration reactivity remain transposed through calcination process as a result of precise flexibility. Hence, the long-term results ensure the expensive MgO cement at desirable outlay [22].

5. Categorizing Discrete Raw Cementitious Materials

Jincheng Yu et al. (2020) suggested magnesium phosphate cement (MPC) with various decisive properties although in real-time application is confined by the reason of cost high raw materials. In order to overcome this, magnesite is combined with dolomite as raw materials to minimize the overall expenditure in MPC production [23]. Also, a quartz powder is imported for calcinations process to chemically incorporate with CaO components in dolomite. In context of calcination temperature and properties of dolomite to quartz mass ratio of calcined raw material were analyzed. The research emphasizes on dolomite ores which is mashed through jaw masher prepare ina terrestrial mill and passed over 74-lm sieve in the past calcination. Consequently, the evaluation of exponential particle size distribution curves of dolomite powders and quartz powders equip for use in manufacture of MPC. This ensures setting time, compressive durability, product hydration, microstructure and soundness of MPC.

Sabouang et al. (2014) have contributed the design of talc from Cameroon as a potential source material for manufacture of cement. The research involved characterized talc sample combined with solution of sodium polyphosphate to develop the cementitious products[24]. In addition of magnesia (MgO) outperform to figure out the effect of convenient MgO products. Finally, overall analysis predicts that talc is a raw material of interest in cementitious products composition. Moreover, the formation of the MgO is a prime aspect for desirable performance of the products.

Kusiorowski and Zaremba (2018) have highlighted the usability of asbestos wastes as Sorel cement fillers. The prime focus of the research is observed through raw materials component as calcined asbestos wastes from 0 to 40 mass %. In this phase, endorse the destruction of an uncertain fibrous structure for the couple of pre-owned asbestos waste such as SEM observation of chrysotile asbestos and raw cement asbestos is also observed [25]. Specimen comprises of reactive magnesium oxide and calcined chrysotile asbestos (cement-asbestos) was processed. In a contrast, the amount of asbestos wastes pointed from 0, 20, or 40 mass %. Subsequently, addition of MgCl₂ solution to the raw materials mass ensures the setting time which can be evaluated based on the Vicat apparatus.

Lipunov and Pervova (2019) has attempted towards slurry as origination of alternative raw material as magnesium oxy-chloride cement. The slurry comprises of magnesium oxide (MgO) and magnesium chloride (MgCl₂) in a mass ratio approximately to the optimal ratio while preparing Sorel cement.

Primarily, the preparation of slurry involved regeneration over mechanical crushing, particle size grinding that shifting between 100–200 μm and fractionating. With relevance to fractionation incorporate of jaw blender and ball mill equipped with twister for collection of dust particle. Also, screen size calibration addresses to fractionate the powder. In short, raw materials can be stored in hermetic containers which in turn avoid the hydration of MgO encompass in the slurry.[26]
Tonelli et al. (2016) has suggested existence of a crystalline hydrated magnesium silicate assemble at regular temperature in the disintegration of cement. In addition, silica gel can be familiar to form inadequately crystallized hydrated calcium silicates of the settled cement under the setting of decomposition phase. To determine magnesium silicate cement over computation of highly-reactive silica source which is termed as micro silica or silica fume moreover the properties of magnesium silicate cements is limited and variable [27]. Table 1 represents the comparison of discrete raw cementitious materials.

| Raw Materials       | Magnesium Oxy-Chloride Cement | Magnesium Oxy Sulfate Cement | Magnesium Phosphate Cement | Magnesium Silica Cement |
|---------------------|-------------------------------|------------------------------|---------------------------|-------------------------|
| MgO+MgCl₂            | MgO+MgSO₄                    | MgO+NH₄H₂PO₄/KH₂PO₄          | MgO+SiO₂                 |

6. Performance parameters of cementitious materials with MgO
In general, composite based cements are widely used materials in field of engineering together with the performance evaluation campaigns of MgO based concrete were conducted through various experimental application. Here, the MgO based cements seems to be more attention in the current research directions also which is suitable for were distinct peculiar engineering construction and its applications. The performance parameters are briefly discussed below.

6.1 Compressive strength: The conception of Portland cement 42.5 graded, fine aggregate as river sand and poly ethylene glycol 400 composite were added with 1%, 3% and 5% of nano-MgO over weight of binder. In contradiction, the observed results of MgO composite figure out the compressive strength of 1% nano-MgO of binder through weight which in turn increased by 103% at 7 days and 80% at 28 days [28].

The porous block included MgO as the binder were analyzed towards the increasing strength impact and enhancement of carbonation. The author recommended better mechanical performance from the least curing duration of one day with the improving potential of carbonation. As a result, brucite peak intensity expose reduced as the carbonation progressed from 1 to 7 days due to the increasing strength [29].
The MgO based cement were gained compression strength 50% higher than Portland cement due to its low hydration. Carbonation and hydration were analyzed by experimental study. The results shows HA increased brucite precipitation and MgO dissolution and DA were reduced water ratio due to increasing CO diffusion [11].

More often the significant of MgO admixtures on the compressive strength of concrete were analyzed at variable curing temperature. The compression strength of the MgO based concrete kept decreased than the core samples at 23°C due to dilution of cement. Subsequently, reactive MgO framed negatively affected strength at 80 °C and 215 °C [30].

In this section, the compressive strength were analyzed and compared with Portland cement is subjected to similar environments which included mechanical performance and micro structure. The carbonation exploits to development regarding compression strength of Portland cement samples. Finally, the highest compression strength at all durability conditions under carbonation with 180 days of curing can be obtained [31]. Figure 1 highlights the compressive strength for various raw cementitious materials.

6.2 Flexural strength: In real time scenarios, the significant impact of MgO on steel fibre were examined through drying shrinkage test and scanning electron microscope. Although the steel fibre composite prepared by MgO and polypropylene fiber reinforcement. The improved flexural and compressive strength has been proved to achieve increasing number of steel fibre quantity. This ensures exponential strength attained by reducing early age shrinkage of reinforced composite [32].

The MgO powder and Flocrete mixtures were prepared to 1, 2, 3 and 4% ratios over the weight of cement and treated by autoclave technique. In connection, the result represents the 2% of MgO through weight of cement and hence it seems to expose increased compressive strength found in 28 day of curing from 81.57 to 148.76. The 2% of MgO leads to interaction in curing, in addition to autoclave treatment emphasizes accelerate the chemical interaction of MgO powder which provides the arbitrary of the interaction larger than the volume that was occupied due to autoclave [33].

The concrete was developed through carbonization technology using activated fly ash has introduced. The effect of fly ash and magnesium oxide based composites were studied towards the flexural failure.
The measured results show that the flexural strength increases during 0-7 days of carbonation curing along with the same increases significantly after 21-28 days of curing. The increasing fly ash content seems to decrease the flexural strength of magnesia carbonized concrete. This necessitates imposing of the flexural strength were increased in carbonized magnesium products due to the impact of Dypingite, Nesquehonite, and Hydro magnesite etc. [34].

6.3 Shrinkage: The prime focus of the survey is to observe the characteristics of drying shrinkage to avoid cracking by employing additives. The thermal shrinkage and autogenous shrinkage of fly ash and Portland cement at low water cement ratio were examined. Therefore the results were pointed the non-wet curing, shrinkage of cement paste that compensated effectively. The effective hydration becomes essential to produce require expansion which compensate the shrinkage on cement paste. The cement pastes that emphasize moderate expansion with increasing sign of temperature. The thermal expansion capitalizes on higher temperature exceeded with development of autogenous shrinkage simultaneously. The pastes shrank rapidly due to the decreasing temperature as a result the hydration of MgO also contributed to the deformation [35].

Sodium silicate, Sodium carbonate and their combinations are used to the development of shrinkage due to the effect of curing conditions in alkali activated concretes. The experimental result was developed based on curing procedure which included heat treatment, non-heat treatment and combination with their sealed and unsealed conditions. Hence, the unsealed and non-heat treated specimens encounters higher shrinkage and heat treatment decreases the shrinkage [36].

The MgO material is an effective expansive agent due to its expansive capacity and controllable reacting speed along with its stable hydration product. The reactive MgO enhances the overall expansion speed and fast hydration. The curing condition comprises of fundamental impact on the hydration speed of MgO and expansion effect is done through hydration in the binder paste. On the other side, the influence of hydration process implicit expensive agent MgO on the shrinkage-compensating mortar with respect to X-ray diffraction Rietveld analysis. This ensures a curing factors include sealed or saturated MgO hydration speed [37].

The excessive drying shrinkage is the major issues in the formation of crack and strength performance over concrete structures. This necessitates two variable reactive grades of MgO together with Portland cement. The autogenous healing performance of MgO samples were higher when compared to Portland concrete samples. The drying shrinkage attempts to crack the restrained end prism. Moreover, the average crack width is proportional to their drying shrinkage properties on prior to healing. Finally, higher concentration of expensive MgO highlights the maximal expansive properties due to the healing crack efficiently. Thus, the expensive MgO were triggered the effective self-healing performance towards the durability and self-improvement [38].

6.4 Durability: The durability of reactive MgO cement concrete with fly ash and blast-furnace slag were investigated under the exposure of sodium sulfate, sodium chloride and seawater over 6 months respectively. The performance of prepared samples were compared to Portland cement-based concrete that subjected to similar conditions. The performance results shows the sulfate attack which led to the maximum reduction, whereas seawater seems to be least influence on strength factors approximate of 6 months. The maximum resistance of reactive MgO specimens in sodium sulfate environment were associated with the hydration and carbonation products to sustain under chemical reactions [39].

The variability of inclined formulation of phosphate ceramics and magnesium phosphate cements to be used as repair mortar. The durability test shows the higher concentration of boric acid. Furthermore, the magnesium phosphate cements is prepared with MgO which seems to be effective toother repair mortars [40]. The flexural strength of Nano-MgO composite equalled 4.66 MPa of 95% and 5.1 MPa of 70% higher than the external MgO composite. The Nano-MgO composites have addressed
homogeneous which supports more compact than the plain composite [41]. The MgO reacts rapidly than the dead burned potential of MgO and the reactivity of MgO based on the treatment conditions and particle size. The ferrous sulphate was improving the strength and durability of reactive MgO cements. The durability performance of MgO cements is difficult to evaluate due to long term studies. The MgO system will undergo the carbonation processes over a long term time frame under natural atmospheric exposure [42]. The maximum ratio of Mg/Ca are influence formation of aragonite and magnesium calcites was precipitate from Mg enriched chloride solutions and sea water [43].

7. Conclusion
The review in this paper examined key aspects, research background in Magnesium oxide (Magnesia - MgO) based cement. Particularly, research has contributed analytical structure on the mechanical strength and durability behaviour of cement plaster and concrete composite formed with increased MgO. In the first phase, the incorporation of MgO is responsible for minimizing porosity when compared to traditional reference blend concealed by accelerated carbonation. In contrast, due to ambient carbonation condition porosity expanded with the addition of MgO. In addition to the carbonation of concrete admixture composed with MgO which seems to be higher while compared to traditional based concrete compound. MgO capitalizes on higher evident with increased MgO soldering levels. Across all series the initial development of concrete mixes increased by expanding the MgO content. The performance parameters of the existing literature is measured in terms of compressive strength, flexural strength, shrinkage and durability. In future research direction would be stimulating to assemble a systematic review of literature beyond expose the existing data to a statistical investigation. Further, based on the variety and content of the reactive MgO in the existing decision concede the advancement of design for predicting distinct properties in large-scale environment.

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