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Review Article

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Approaches for Dental Gypsum Modifications: A Narrative Review

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Abstract
Despite their widespread use in dental applications, gypsum materials have limitations, including low compressive strength, inadequate surface hardness, and dimensional instability. Therefore, this paper reviews current approaches to modifying dental gypsum and examines the properties of the resulting modified materials. Additionally, this study investigates the effects of physical and chemical treatments on the performance of dental gypsum. While physical treatments involved controlling the drying system, adjusting the mixing water, and using disinfectants, chemical modifications were achieved by incorporating various additives. An electronic search for data published between 2000 and 2024 was conducted using the Web of Science, ScienceDirect, Scopus, PubMed, and Google Scholar databases. The keywords included gypsum materials, dental plaster, stone models, gypsum composites, slurry water, setting expansion, and chemical disinfection. A total of 426 records were retrieved from various databases, of which 307 were screened, yielding 46 relevant to the research objectives. The modifications made by physical methods were insufficient for producing satisfactory products. However, the addition of polymeric and fibrous additives led to significant improvements in the mechanical properties of the resulting gypsum. Positive results were achieved by incorporating various ceramic fillers, which enhanced the compressive strength of gypsum composites. Despite its promising benefits, this technique has not been widely used in practice.

Keywords:
compressive strength; dental plaster; dimensional accuracy; disinfectants; gypsum materials

1. Introduction

Gypsum materials are widely used in dentistry as white powders, chemically known as calcium sulphate hemihydrate ($CaSO_4 \cdot ½H_2O$). According to the ISO for dental gypsums, the materials are classified into five types (Figure 1). Type I represents impression plaster for taking impressions and bite registration, whereas type II corresponds to dental plaster for study models and mounting purposes. Types III, IV, and V are dental stones for working casts, high-strength dies, and high-strength and high-expansion dies, respectively [1,2]. Although these materials have similar chemical compositions, they differ in particle size, shape, and porosity due to different manufacturing procedures, thereby exhibiting disparate physical and mechanical performance [3,4]. The properties of five types of gypsum materials are presented in Table 1. Although dental Plaster is extensively utilized in dental clinics and laboratories to create casts [5], the time required and surface porosity could lead to deferring laboratory processes and producing imprecise anatomical models [6]. Therefore, modifying conventional plaster and fabricating gypsum composites could effectively address such issues and yield enhanced products.

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Construction gypsum can effectively be used as an alternative product to Type II dental plaster [7]. Flue gas desulfurization (FGD) gypsum has been studied as a potential replacement for natural gypsum in dental materials [8]. To assess their effects on the physical and mechanical properties of the resulting gypsum, several parameters were investigated, including acid treatment, particle size, and synthesis process. The results indicated that contaminants could be removed from FGD gypsum, while its compressive strength was enhanced by an acid treatment lasting 15 minutes. The compressive strength of the tiny particles was higher than that of the bigger ones. Sulphuric acid treatment of FGD gypsum resulted in a lighter hue and a rough, porous surface for the crystal structure. The synthetic substance, known as dental plaster, was categorized as types 1 and 2 according to its low compressive strength level.

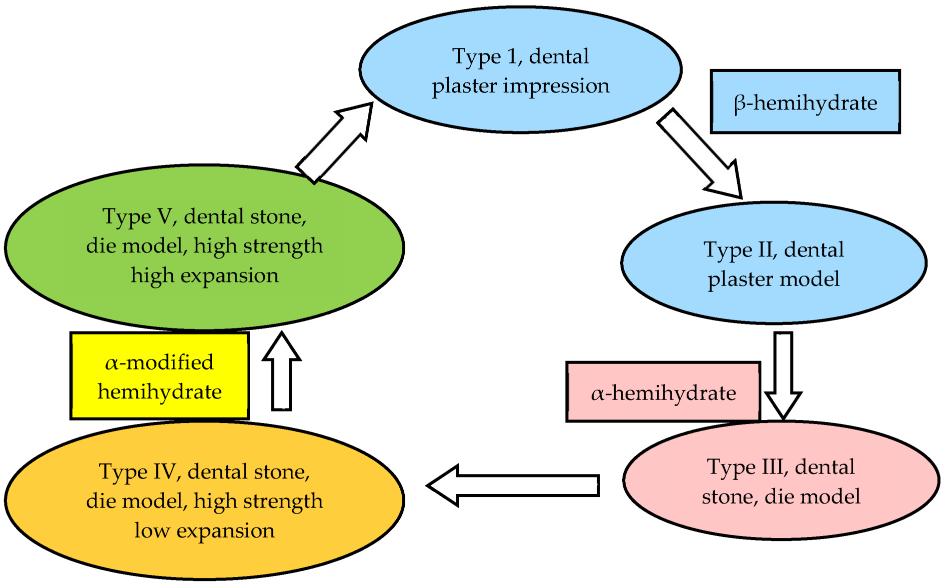

Figure 1: Various types of dental gypsums.

Table 1: Characteristics of different types of gypsum products.

Type	Composition	Preparation Method	* W/P Ratio	* Setting Time (min)	* Setting Expansion (2 h; %)	* Compressive Strength (1 h; MPa)
I	Alpha hemihydrate	Dry calcination (110–120 °C)	0.50–0.75	4 ± 1	0.00–0.15	4.0
II			0.45–0.50	12 ± 4	0.00–0.30	9.0
III	Beta hemihydrate	Wet calcination (110–120 °C)	0.28–0.30	12 ± 4	0.00–0.20	20.7
IV		Wet calcination + 30% calcium chloride	0.22–0.24	12 ± 4	0.00–0.10	34.5
V			0.18–0.22	12 ± 4	0.00–0.30	48.3

* Properties of five types of gypsums as stated by American Dental Association Specification No. 25.

Achieving successful dental restorations requires high accuracy in reproducing the detailed anatomy of the oral cavity. Dimensional accuracy is a prerequisite characteristic for dental gypsum, which leads to minimizing laboratory faults, therefore reducing the insertion time of prosthodontics. The expansion of traditional gypsum materials should be controlled to certify their accuracy and reliability for dental applications [9]. Such behavior depends on the composition of the gypsum and the calcination method [10]. Samra et al. [11] inferred that the conventional gypsum casts are comparable in accuracy to the digital models. However, these materials continue to exhibit deficiencies, including low compressive and ten-

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sile strength, poor abrasion resistance, inadequate surface hardness, and general susceptibility to damage [9,12,13].

In general, there are strong demands to improve gypsum properties to replace traditional materials. Gypsum products can mainly be developed using physical and chemical techniques. Physical enhancements can be achieved by releasing residual water and accelerating the drying time of wet-poured gypsum. Therefore, the drying techniques could play an essential role in promoting the gypsum characteristics [14–17]. In addition, post-pouring time could be an effective factor influencing the mechanical properties of dental gypsum. As reported by Cesero et al. [18], surface roughness, tensile strength, and compressive strength increased significantly over time after pouring. However, the promoted attributes using physical methods were insufficient to generate satisfied products [6,14,15].

Dental materials are commonly reinforced with ceramic additives and fabricated as composite materials [19, 20]. Hence, another approach to improving the behavior of gypsum materials involves the incorporation of various fillers. Ma et al. [9] reported that the properties of gypsum products can be enhanced by introducing different types of reinforcing agents and nanofillers, which can provide high precision for prosthodontic applications. Previous investigations [21,22] demonstrated that the incorporation of nano-silica into the gypsum matrix enhanced the surface hardness with no notable effect on the compressive strength of gypsum composites. Other filler particles, such as alumina and marble powders, have also been incorporated into dental plaster gypsum, resulting in improved physical properties [3,12]. However, insufficient data in the surveyed literature have been found on strengthening dental plaster gypsum by fabricating composites. Thus, assessing processing techniques and producing accurate gypsum composites with well-developed mechanical and physical characteristics is necessary to achieve successful dental restorations. Therefore, this review aims to shed light on the current state of research on state-of-the-art physical strategies for enhancing the performance of gypsum products, including drying methods, types of mixing water, and disinfection. The incorporation of numerous additives into the gypsum matrix and their effects on gypsum behavior are also described.

2. Review Methodology

An electronic search for data published from 2000 to 2024 was conducted across the Web of Science, ScienceDirect, Scopus, PubMed, and Google Scholar databases. The used keywords contained gypsum materials, dental plaster, stone models, gypsum composites, slurry water, setting expansion, and chemical disinfection. Moreover, reference lists of earlier articles have been screened to identify additional studies. Each work that suggested a possible counterpart or inappropriate exclusion standards, based on the evidence available in the title, was assessed.

The selection criteria for the surveyed records are presented in Figure 2. The first assessment was conducted according to the article's title. Then, checking the abstracts of the relevant titles to estimate their relation. Inclusion criteria consisted of studies evaluating the mechanical properties (surface hardness, compressive, and flexural strength) and accuracy of gypsum obtained by accelerating the drying period, altering the mixing water, developing the mixing technique, and incorporating various additives. After that, the relevance of full-text documents to the work topic, as indicated by their associated abstracts, was evaluated. Irrelevant works, abstracts, letters, and case reports were removed. Articles for testing 3D-printed dental casts and gypsum filler were omitted. Only studies published in English were reviewed.

3. Discussion

A total of 426 records were obtained from various sources, of which 307 were screened. Finally, 46 articles were related to the work objectives (Figure 2). The innovative mixing techniques for improving the behavior of dental gypsum were involved [6,23]. Thirty-four articles addressed the physical treatment of gypsum materials through control of the drying period, modification of the mixing water, and incorporation of disinfectants, as summarized in Table 2. Twelve articles addressed the chemical modification of dental gypsum by the incorporation of various additives (Table 3).

3.1. Physical Treatments of Gypsum

3.1.1. Drying System

Gypsum dehydration and dryness could be favorable processes for strengthening gypsum products and reducing the time required at the dental laboratory. The effect of drying techniques on the abrasion resistance of three types of dental stone has been investigated [16]. The outcomes revealed that microwave drying displayed higher abrasion resistance of dental stones and achieved the lowest weight loss (0.295 g). In contrast, the reductions in samples' weight were increased when hot air oven and open-air drying were applied (0.808 g, 1.217 g, respectively). The heat could lead to highly prismatic, dense crystals with lower porosity, thereby increasing abrasion resistance. Drying dental stones using microwave energy resulted in a considerable reduction in compressive strength. This behavior was attributed to the presence of porosity, cracks, and holes generated from the water evaporation after exposure to microwave irradiation [15]. Other studies reported that microwave drying had no significant effect on the compressive strength or dimensional stability of dental stones [14,17].

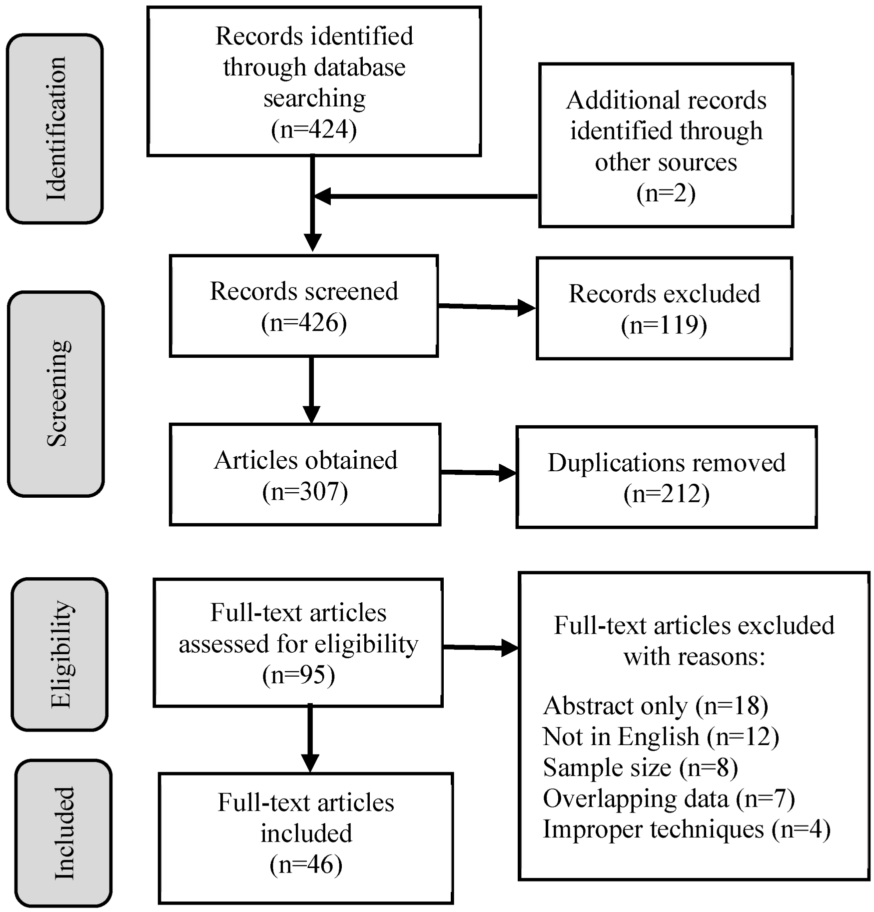

Figure 2: Flowchart of selection criteria of the assembled articles.

3.1.2. Types of Mixing Water

Changes in water content affected the dimensional accuracy of gypsum materials, potentially compromising the handling of the set plaster and the precision of the resulting prosthodontic fit [24]. Moreover, higher W/P ratios could certainly result in lower bulk density, diminished compressive strength, and raised hygroscopic expansion and porosity [25,26]. Earlier studies [27,28] examined the effect of using excess water beyond the recommended water-to-powder (W/P) ratio on the physical and mechanical properties of dental gypsum. The findings indicated that increased water content led to inferior properties due to larger crystals and higher stress concentration at crystal boundaries, resulting in earlier fracture at lower loads and reduced strength.

Regarding different types of mixing water, Proença et al. [29] evaluated the effects of distilled, tap, and mineral water on the compressive strength, dimensional stability, and surface roughness of dental stone. They found that these types of water did not affect the tested properties of the dental stone. Ozonated water has also been examined to establish its impact on the physical properties of dental stone [30]. It has been found that utilizing ozonated water increased the surface roughness of gypsum materials. Slurry water, obtained from soaking gypsum models or from cast trimming, is another type of mixing water. It is commonly used in the preparation of dental casts due to its effectiveness in enhancing surface hardness [31], increasing setting expansion, reducing compressive strength [32,33] and the initial setting time of gypsum [33]. In addition, using the slurry water resulted in a lowering of the water/powder (W/P) ratio (0.42), whereas the ratios of distilled, mineral, and deionized water to powder were 0.64, 0.50, and 0.52, respectively [34]. This behavior was attributed to accelerated crystallization nucleation and the presence of calcium sulphate in slurry water, which improves wetting of plaster crystals [34]. These findings are consistent with a previous study, which reported that slurry water caused a significant reduction in wet compressive strength compared with the control group [35].

In addition to the water type, the mixing method could also influence the characteristics of the resulting materials. For that, the effects of three different ways of mixing (hand, vacuum mixing, and shaking) on the mechanical behavior of dental stones have been evaluated [36]. The results indicated that the tested properties were not affected by the mixing techniques. Other studies reported that shake mixing increased the fluidity and compressive strength and reduced the setting time, with no effect on marginal adaptation [6,23].

3.1.3. Disinfectant Solutions

Disinfectants are mixed with gypsum as a water substitute or as an antimicrobial agent to control cross-infection, without adverse effects on the performance of gypsum products. However, a reduction in the strength properties of dental stones was observed due to modifications in the crystal structure, which constrain the crystals' ability to intermesh [37]. Oancea et al. [38] replaced water with disinfectants and tested their effects on the mechanical properties of dental stone. They stated that replacing water with chemical disinfectants affects dimensional accuracy and increases the brittleness of the resultant materials. Spraying dental stones with various chemical disinfectants can significantly reduce Vickers hardness, due to the porosity generated from reactions occurring when the gypsum is humidified [39]. In addition, the effects of several disinfectants on the physical properties, such as dimensional accuracy, detail reproduction and setting time of dental stone, have been analyzed [40]. The findings indicated that the addition of sodium hypochlorite significantly reduced setting time, dimensional accuracy, and the fidelity of reproduced details. Such reduction was attributed to the formation of low-solubility salts which modified the nucleus of crystallization, leading to delaying the setting time and shrinking the gypsum during the setting. These outcomes are consistent with those of others who declared that soaking the gypsum casts in sodium hypochlorite significantly reduced their surface hardness [41]. Peracetic acid and sodium hypochlorite have also been used as disinfectants, and no notable effects on dimensional accuracy and details reproduction of dental stones were observed [14,42].

Table 2: Several physical treatments used to modify the gypsum materials.

Treatment	Gypsum Type	Method	Comment	Ref.
Microwave Drying	Type IV dental stones	Dried at 2450 MHz, 900 W for 150 s.	Reduction in compressive strength.	[15]
		Dried at 900 watts for 5 min.	Higher abrasion resistance.	[16]
	Dental stone	Dried at 2450 MHz, 900 W for 5 min.	No notable effect on the compressive strength and dimensional stability of dental stones.	[14]
	Type IV dental stones	Dried at 800 W for 5 min.		[17]
Types of mixing water	Type IV and V gypsum	Tap, mineral, and distilled water	Did not influence the analyzed physical and mechanical properties.	[29]
	Type II and III gypsum casts	Diluted slurry water.	Increase in surface hardness	[1]
	Type III gypsum	Slurry water.	Shorten the setting time, decrease the compressive strength, and improve the dimensional change.	[32]
	Plaster/Stone	Slurry water prepared with a volume ratio of 16% and 2%	Decreased the initial setting time. Increased the expansion amount to a great measure in the first 2 and 5 h	[33]
	Type IV dental stones	Slurry with distilled water and slurry with 0.525% sodium hypochlorite	Significant increase in linear dimension and a substantial decrease in wet compressive strength.	[35]

Table 2: *Cont.*

Treatment	Gypsum Type	Method	Comment	Ref.
Disinfectant Solutions	Type III & IV dental stone	0.525% sodium hypochlorite + 2% glutaraldehyde	Adversely affected the compressive and tensile strength.	[37]
	Type IV dental stone	0.525% sodium hypochlorite and 2% chlorhexidine gluconate	Alter the setting expansion value to make the model dental stone brittle.	[38]
	Type III and IV dental stones	1% Virkon and 0.525% hypochlorite	Decreased surface hardness.	[39]
	Type III dental stone	1.5% K_2SO_4 solution	Improved the surface hardness and compressive strength. Reduced surface roughness	[43–45]

Earlier studies [43–45] investigated the effects of incorporating potassium sulfate solution on the surface hardness, roughness, and compressive strength of dental stones. Although a reduction in the surface roughness of gypsum after adding 1.5% potassium sulphate was found, improvements in compressive strength and surface hardness were reported. Such enhancement was attributed to the formation of syngenite (K2Ca (SO4)2·H2O), which promotes larger crystallization nuclei and reduces gaps between gypsum crystals. This finding aligns with previous studies, which reported that using hypochlorite as an alternative to distilled water had no adverse effect on the compressive strength, setting expansion, or setting time of dental stone [35].

3.2. Chemical Modifications

Most chemicals added to dental gypsum accelerate the dissolution of hemihydrate, thereby expediting the setting reaction. It is well known that potassium sulphate is widely used as an accelerator at a concentration of 2% [46]. However, the added chemical salts act as contaminants and reduce crystalline cohesion, thereby decreasing the strength of the gypsum materials [1]. Another suggested treatment is the use of polymerizable monomers, which could enhance the durability of gypsum products. The production of the polymer phase by polymerizing the monomer improves the toughness and strength by occupying the voids in the dental gypsum [2]. Cyanoacrylate and various die-hardeners have been applied to treat the gypsum cast [47,48]. Although surface hardness improved, the mechanical properties could not be enhanced. Therefore, incorporating several types of fillers into the gypsum matrix could be a promising approach to improve the performance of the resultant gypsum composites. The effectiveness of different inclusions on the behavior of gypsum composites is summarized in Table 3.

3.2.1. Polymerous Reinforcing Agents

The effects of various resins on the performance of dental gypsum have been investigated, yielding conflicting results. Different types of resins, such as rosin and gum Arabic, have been used as fillers and incorporated into the gypsum plaster materials to evaluate their characteristics. The results revealed that these additives can lead to improving the mechanical behavior of dental gypsum [46,49]. However, the detrimental effect of gum Arabic on the mechanical attributes of dental stones has been reported [37,50]. Such behavior was attributed to excess water kept in the set material. Furthermore, the effect of adding epoxy to dental stones was investigated [51]. The findings indicated that epoxy resin could improve the abrasion resistance and flexural properties of gypsum materials. The epoxy absorbed much more energy before fracture, suggesting it should be less susceptible to breakage. The setting shrinkage was higher than the setting expansion of the experimental gypsum materials. Another study was designed to assess the mechanical and physical characteristics of dental plaster materials by including different concentrations of ground acrylic dust [52]. It has been concluded that the control group had lower initial and final setting times. The shortened setting time of modified dental plaster was attributed to the incorporated level of acrylic powder and its greater water-absorption capacity. The impact of cyanoacrylate on the surface hardness of dental stone has also been determined [53]. The findings showed that applying cyanoacrylate resin to the surface of type IV dental stone can increase its surface hardness.

3.2.2. Fibrous Additives

Incorporating fiber fillers can enhance the mechanical properties of gypsum materials. Kati et al. [49] performed a study to investigate the impact of glass fibers on the compressive strength of dental stones. They postulated that the compressive strength of gypsum materials was substantially improved by impregnating glass fibers. In a similar situation, the inclusion of chopped carbon fibers in gypsum plaster resulted in remarkable developments in compressive and flexural strength [54,55]. These enhancements were attributed to the high tensile strength of the fibrous fillers, which hindered the crack propagation. Significant improvements in compressive strength were also obtained by adding chopped copper fibers to gypsum plaster [56,57]. The compressive strength of gypsum composites reduces as the W/P ratio rises. However, a recent study [58] has been conducted to examine the influence of the impregnation of paper pulp on the physical and mechanical properties of gypsum plaster. Paper pulp is a cellulosic fibrous material extracted from wood or waste paper. It has been reported that the filled gypsum exhibited lower density, shorter working time, and longer setting time. In addition, compressive and flexural strengths were reduced due to the hydrophilic nature of the fillers and increased moisture content. Correspondingly, the performance of the resulting gypsum composites was negatively impacted by the addition of natural fibers [59]. The hardness of the gypsum composite decreased with increasing fiber content, due to the development of a more porous structure.

3.2.3. Ceramic Fillers

Although the addition of nano-silica reduced the surface roughness of dental stone by filling the interparticle voids, no significant changes were observed in the compressive or tensile strength of the gypsum composites [22]. Other investigations [21,60] concluded that remarkable enhancement in surface hardness and reduced linear dimensional changes of dental stone composites were observed when silica nanofillers were impregnated. Fumed silica fillers have also been incorporated into the gypsum matrix, leading to an elevation in the density and compressive strength of the gypsum composites by 100% and 52%, respectively [25]. Such increments were attributed to the chemical effect of fumed silica on the water/gypsum reaction, which strengthens the intercrystalline bonds within gypsum crystals.

Previous studies [12,61] have also evaluated the effectiveness of incorporating alumina fillers into dental plaster. The findings showed that the compressive strength and surface hardness of plaster composites increased from 7.8 to 70 MPa and from 64.4 to 124.3, respectively, whereas the setting expansion decreased from 0.12% to 0.06% [61]. This was attributed to the strengthening effect of the ceramic fillers and the reduced gypsum content in the reinforced specimens, which decreased the formation of dihydrate crystals and, consequently, the generation of internal porosity. Different fillers have also been employed to modify the gypsum materials. As a result, improved flexural and compressive strength, along with decreased linear expansion, were achieved [9]. White Portland cement was also introduced as an additive to reinforce gypsum plaster [62]. The presence of white cement at an optimal 4.0% w/w was found to support other significant properties, such as compressive strength and setting time, while mitigating gypsum's weaknesses, including its relatively low hardness and water solubility.

From an ecological perspective, studies have explored the effects of incorporating waste materials, such as blast furnace slag, unburnt rice husk, and calcium carbonate, as fillers in plaster gypsum [63]. The waste materials extend the setting time and decrease the density and compressive strength. These additives are placed into the gaps between the gypsum particles without reacting with the gypsum matrix. Marble powder has also been studied as a reinforcement for dental gypsum [3]. This powder is a waste byproduct generated during the cutting of marble blocks. Its incorporation significantly improved the physical properties of gypsum composites, including density and flowability.

Table 3: Types of various reinforcing agents used in gypsum composite construction.

Additives	Loadings (%)	Gypsum Type	W/P Ratio	Comment	Ref.
Marble powder	1, 3, 6, 9	Plaster	0.5	Improved density and fluidity with reduced porosity.	[3]
Alumina	15	Plaster	0.5	Higher compressive strength and surface hardness with lower setting expansion.	[12]
Nano-silica	2	Stone	-	Enhanced surface hardness. Reduced dimensional changes.	[21]
	1, 5		0.19–0.2	Lowering surface roughness. No significant effect on tensile and compressive strength.	[22]

Table 3: *Cont.*

Additives	Loadings (%)	Gypsum Type	W/P Ratio	Comment	Ref.
Fumed silica	0.6, 1.2	Local gypsum (Juss)	0.3–0.4	Decreasing density and compressive strength. Higher porosity level.	[25]
Glass fibers	1	Plaster and stone	0.25	Significant increase in compressive strength	[49]
pulverised acrylic	0.5, 1, 5, 10	Plaster		Higher compressive strength and decreased setting time	[52]
Chopped carbon fibers	0.2, 0.4	Plaster	0.5–0.6	Fiber increased compressive strength and modulus of rupture. Deterioration took place with increased w/p ratios.	[54,55]
Natural fibers	1, 3, 5	Plaster		Lower surface hardness and thermal conductivity	[59]
Nano-silica	0.5, 1, 2	Stone (type IV)	0.24	Improved surface hardness. Significant antimicrobial activity.	[60]
Nano-alumina	10	Plaster	0.5	Enhanced compressive strength and surface hardness.	[61]
rice husk, calcium carbonate	0.2–10	Plaster	-	Slight increase in compressive strength.	[63]

4. Prospective

Reinforced gypsum materials hold promise for the production of low-cost materials and the development of innovative products. Currently, numerous attempts have been carried out to improve the gypsum properties and explore the gypsum behavior after filler inclusion. Furthermore, additional studies are needed to investigate the potential interactions between reinforcing agents and the gypsum matrix. Filler treatment and reactivity could play a crucial role in enhancing the composites' performance [64]. Selection of the efficient filler type, size, and form could also be a key factor in enhancing the performance of the resultant gypsum composites. Although the application of strengthening dental gypsum by impregnating it with various additives is quite limited, this technique could be the method of choice for developing gypsum products.

5. Conclusions

Gypsum dehydration improved its surface characteristics and reduced the time required in the dental laboratory, but it has been observed to negatively affect mechanical properties. Although dental gypsum can be modified by using different types of mixing water and disinfectants, unstable performance and inferior mechanical properties have been reported. However, promising results have been achieved with the inclusion of various ceramic fillers. Improving the plaster's properties can reduce its usage and lower costs. Although the use of this technique could play an essential role in improving the behavior of dental gypsum, it has not been extensively used in practice. Hence, further investigations are needed before gypsum composites can be recommended as an alternative to conventional dental gypsum.

List of Abbreviations

ISO	International Organization for Standardization
FGD	Flue Gas Desulfurization
MPa	Megapascal (unit of compressive strength)
MHz	Megahertz (microwave frequency unit)
W/P ratio	Water-to-Powder ratio
w/w	Weight by weight (concentration ratio)
W	Watt (the standard unit of power)

Author Contributions

Data collection, visualization, and writing—original draft preparation: N.W.E.; study conception and design: F.K.; review and editing of the manuscript: M.M.A.; supervision and project administration: Z.A.A. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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AI Declaration

The authors confirm that no AI tools were used to generate any content of this manuscript.

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