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Review Article

Approaches for Dental Gypsum Modifications: A Narrative Review

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Abstract

Despite the widespread use of gypsum materials in dental applications, these materials have some limitations, including low compressive strength, inadequate surface hardness, and dimensional instability. Therefore, this paper reviews the current systems for modifying dental gypsum and discusses the characteristics of the resulting gypsum materials. Additionally, the work examines the effects of physical and chemical treatments on the performance of dental gypsum. While the physical treatment relied on controlling the drying system, mixing water, and using disinfectants, the chemical modifications came from 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 the various databases, of which 307 were screened, resulting in 46 that were relevant to the research objectives. The modifications through physical methods were inadequate in producing satisfactory products. However, adding polymeric and fibrous additives led to significant improvements in the mechanical properties of the resulting gypsum. Positive results were achieved by incorporating different types of ceramic fillers, which enhanced the compressive strength of gypsum composites. Despite the promising benefits of this technique, it has not been extensively used in practice.

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

1. Introduction

Gypsum materials are widely used in dentistry as white powder, chemically known as calcium sulphate hemihydrate ($CaSO_4 \cdot \frac{1}{2} H_2O$). 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 for dies, and high-strength and high-expansion for dies, respectively [1, 2]. Although these materials have similar chemical compositions, they vary in their particle size, shape, and porosity level 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 utilised 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 efficiently help tackle such issues and generate enhanced products.

Construction gypsum can effectively be used as an alternative product to Type II dental plaster [7]. Flue gas desulfurisation (FGD) gypsum has been studied as a potential replacement for natural gypsum in dental materials [8]. To ascertain their effects on the physical and mechanical properties of the resulting gypsum, a number of parameters were investigated, including acid treatment, particle size, and synthesis process. The results showed that contaminants could be removed from the FGD gypsum while increasing its compressive strength with an acid treatment duration of 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 categorised as types 1 and 2 according to its low compressive strength level.

Attaining felicitous dental restorations entails good accuracy in the detailed reproduction of the oral cavity. Dimensional accuracy is a prerequisite characteristic for dental gypsum, which leads to minimising laboratory faults, therefore reducing the insertion time of prosthodontics. Setting expansion of traditional gypsum materials should be controlled to certify their accuracy and reliability for dental applications [9]. Such behaviour 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 still suffer from deficiencies such as poor compressive and tensile strength, low abrasion resistance, inadequate surface hardness, and are simply vulnerable to damage [9, 12, 13].

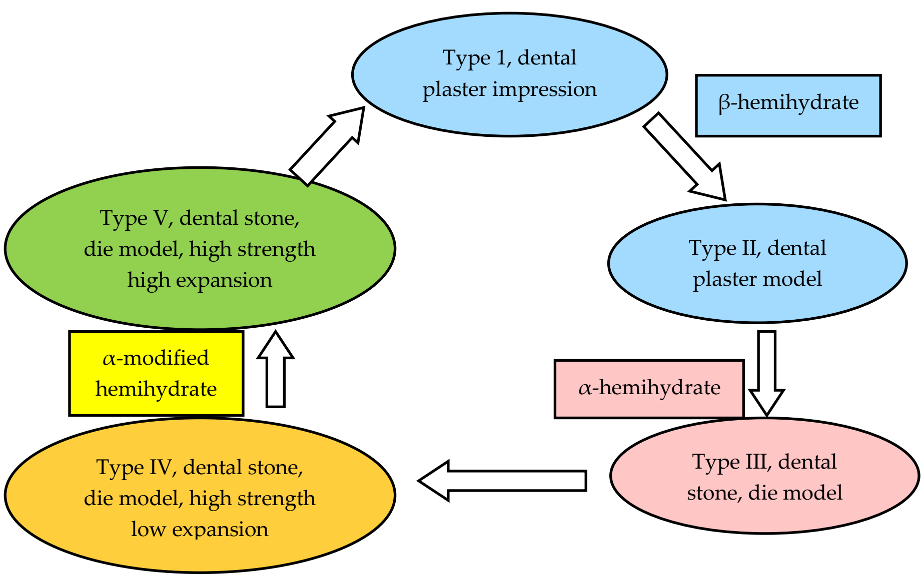

Figure 1: Various types of dental gypsums.

Table 1: Characteristics of different types of gypsum products.

Type	Composition	Preparation method	* W/P ratio	* Setting time (min)	* Setting expansion (2 hrs; %)	* Compressive strength (1 hr; MPa)
I		Dry calcination	0.50-0.75	4 ± 1	0.00-0.15	4.0

II	Alpha hemihydrate	(110-120 ºC)	0.45-0.50	12 ± 4	0.00-0.30	9.0
III	Beta hemihydrate	Wet calcination (110-120 ºC)	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

In general, there are crucial demands for improving the gypsum properties to replace the present traditional materials. Gypsum products can mostly be developed using physical and chemical techniques. Physical enhancements could be reached by releasing residual water and accelerating the drying period of wet-poured gypsum. Therefore, the drying techniques could play an important 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 were dramatically raised with time after pouring. However, the promoted attributes using physical methods were insufficient to generate satisfied products [6, 14, 15].

Dental materials are commonly strengthened by adding ceramic additives and fabricated as composites [19, 20]. Hence, another approach to improving the behaviour of gypsum materials comprises the inclusion of various fillers. Ma *et al.* [9] stated that the characteristics of gypsum products can be enhanced by impregnating different types of reinforcing agents and nanofillers, which could offer good precision for prosthodontics. 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 impregnated with dental plaster gypsum, and enhanced physical properties were presented [3, 12]. However, not enough data in the surveyed literature have been found about strengthening dental plaster gypsum by fabricating composites. Thus, assessing the processing techniques and producing accurate gypsum composites with developed mechanical and physical characteristics is required to attain successful dental restorations. Therefore, this review aims to shed some light on the current status of research on the various state-of-the-art physical strategies for enhancing the performance of gypsum products, such as drying methods, types of mixing water, and disinfection. The incorporation of numerous additives into the gypsum matrix and their effectiveness on gypsum behaviour are also described.

2. Review Methodology

An electronic search for data published from 2000 to 2024 was carried out through 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 according to the evidence obtainable in the title was assessed.

The selection criteria for the surveyed records are presented in Figure 2. The first assessment was attained according to the title of the article. 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, an evaluation of the relevance of full-text papers with the related abstracts to the work topic was performed. 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.

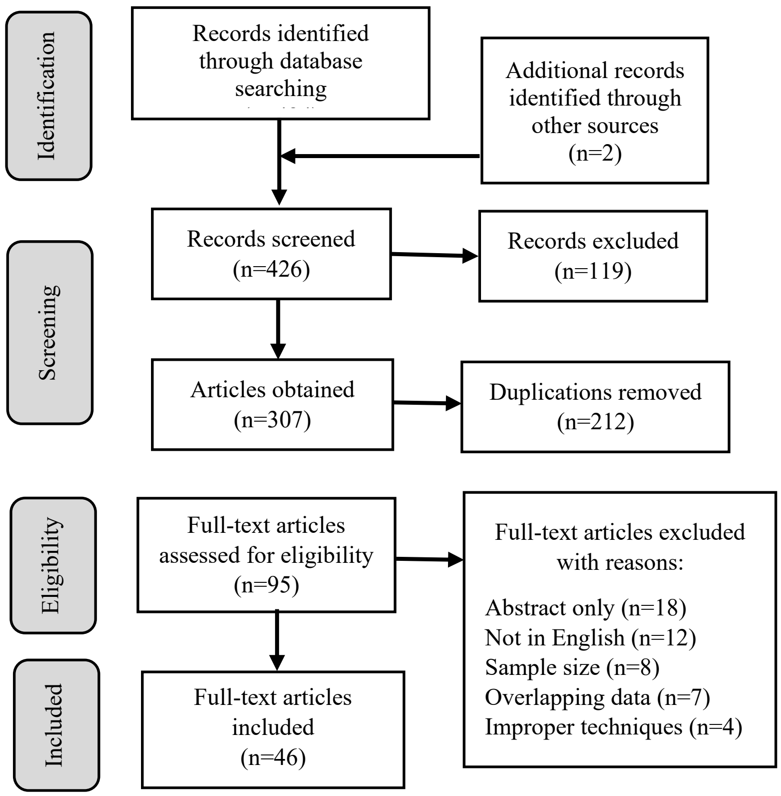

Figure 2: Flowchart of selection criteria of the assembled articles.

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 behaviour of dental gypsum were involved [6, 23]. Thirty-four articles dealt with the physical treatment of gypsum materials by controlling the dryness period, altering the mixing water, and incorporating disinfectants, as summarised in Table 2. Twelve articles addressed the chemical modification of dental gypsum by the inclusion of various types of additives (Table 3).

3.1. Physical treatments of gypsum

3.1.1. Drying system

Gypsum dehydration and dryness could be favourable 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 stones 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 high prismatic and dense crystals with decreasing porosity, thus increasing the abrasion resistance. Drying dental stones using microwave energy caused a considerable reduction in compressive strength. This behaviour was attributed to the presence of porosity, cracks, and holes generated from the water evaporation after exposure to microwave irradiation [15]. While others stated that there was no notable effect of microwave drying on the compressive strength and dimensional stability of dental stones [14, 17].

3.1.2. Types of mixing water

Alteration in water content influenced the dimensional accuracy of gypsum material, which could compromise the appropriate handling of the set plaster and the precision of the fit of the constructed prosthodontics [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 works [27, 28] investigated the influence of excessive water for the recommended W/P ratio on the physical and mechanical properties of dental gypsums. The findings clarified that increased water content led to inferior evaluated characteristics due to increasing crystal size and higher localising stress on the crystal boundary, resulting in rapid fracture at lower loads, thereby poor strength.

Regarding the various sorts of mixing water, Proença *et al.* [29] evaluated the influence of three types of water (distilled water, tap water, and mineral water) on the compressive strength, dimensional change, and surface roughness of the dental stone. They found that these types of water did not exhibit any effect on the tested properties of the dental stone. Ozonated water has also been examined to establish its effects on the physical properties of dental stone [30]. It has been found that utilising ozonated water increased the surface roughness of gypsum materials. Slurry water is another type of water obtained after soaking the gypsum models in water or trimming the casts. The slurry water is widely used as mixing water to produce dental casts because of its efficient impact in improving the 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 deionised water to powder were 0.64, 0.50, and 0.52, respectively [34]. This behaviour was attributed to accelerating the nucleation of crystallisation and the existence of calcium sulphate in the slurry water, which improves the wetting of plaster crystals [34]. These findings were in agreement with a previous study that stated that slurry water caused a notable drop in wet compressive strength compared with the control group [35].

In addition to the water type, the mixing method could be another factor that affects the characteristics of the resultant materials. For that, the effects of three different ways of mixing (hand, vacuum mixing, and shaking) on the mechanical behaviour of dental stones have been evaluated [36]. The results declared that the tested properties were not affected by the mixing techniques. Others inferred 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 antimicrobial agent to control cross-infection, but without adverse effects on the performance of gypsum products. However, a reduction in the strength properties of dental stones was recorded due to the alteration of the crystal structure, which constrains the crystals' ability to intermesh [37]. Oancea et al. [38] replaced water with disinfectants and tested its effects on the mechanical properties of dental stone. They declared that substituting water with chemical disinfectants affects the dimensional accuracy and increases the brittleness of resultant materials. Spraying the dental stones with various chemical disinfectants could lead to a remarkable reduction in the Vickers hardness because of the existing porosity formed due to the reaction that occurred after humidifying the gypsum [39]. In addition, the effects of several disinfectants on the physical properties, such as dimensional accuracy, reproduction details, and setting time of dental stone, have been analysed [40]. The findings revealed that the inclusion of sodium hypochlorite considerably decreased setting time, dimensional accuracy, and reproduction details. Such reduction was attributed to the formation of low-soluble slats which modified the nucleus of crystallisation, leading to delaying the setting time and shrinking the gypsum during the setting. These outcomes are consistent with 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, 900W 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 analyzsed 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 setting time, decrease compressive strength, and increase dimensional change.	[32]
	Plaster/Stone	Surry 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 hours	[33]
	Type IV dental stones	Slurry with distilled water and slurry with 0.525% sodium hypochlorite	Significant increase in linear dimension and a significant decrease in wet compressive strength.	[35]
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 value of the setting expansion and cause the model dental stone to be 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] have been conducted to examine the effect of the inclusion of potassium sulphate 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 ascribed to the formation of syngenite ($K_2Ca(SO_4)_2 \cdot H_2O$), which has a bigger nucleus size, leading to a reduction in the gaps between gypsum crystals. This finding is in agreement with others who decided that using hypochlorite as an alternative solution to distilled water showed no negative influence on compressive strength, setting expansion, or setting time of dental stone [35].

3.2. Chemical Modifications

Most chemicals that are added to dental gypsum accelerate the dissolution of hemihydrate, which expedites the setting reaction. It is well-known that potassium sulphate is extensively employed as an accelerator at a concentration of 2% [46]. However, the added chemical salts act as contaminants and reduce the crystalline cohesion, leading to a lowering in the strength of the gypsum materials [1]. Another suggested treatment is the use of polymerisable monomers, which could enhance the durability of gypsum products. The production of the polymer phase by polymerising 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 improving surface hardness was reported, the mechanical properties could not be enhanced. Therefore, incorporating several types of fillers into the gypsum matrix could be a promising method to develop the performance of resultant gypsum composites. The effectiveness of different inclusions on the behaviour of gypsum composites is summarised in Table 3.

3.2.1. Polymerous reinforcing agents

The effects of various resins on the performance of dental gypsum were investigated, and controversial findings were presented. 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 behaviour 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 behaviour was attributed to excess water kept in the set material. Furthermore, the addition of epoxy to dental stones was investigated [51]. The findings showed that epoxy resin could develop the abrasion resistance and flexural properties of gypsum materials. The epoxy absorbed much more energy before fracture and 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 ascribed to the incorporated level of acrylic powder and its higher capacity for water absorption. 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

Impregnating fibre fillers could lead to improving the mechanical characteristics of gypsum materials. Kati et al. [49] performed a study to investigate the impact of glass fibres on the compressive strength of dental stones. They postulated that the compressive strength of gypsum materials was substantially improved by impregnating glass fibres. In a similar situation, the inclusion of chopped carbon fibres 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 disclosed that the filled gypsum exhibited lower density, shorter working time, and longer setting time. In addition, the compressive and flexural strengths of gypsum composites were reduced due to the hydrophilic nature of the fillers and the increasing moisture content. Correspondingly, the performance of the resulting gypsum composites was negatively impacted by the addition of natural fibers [59]. Due to the promotion of the porous structure, the hardness values in the gypsum composite dropped as the fiber additive ratio increased

3.2.3. Ceramic Fillers

Although the addition of nano-silica led to a decrease in the surface roughness of dental stone due to occupying the interparticle voids of the gypsum by the filler nanoparticles, no changes in the compressive and tensile strength of the gypsum composites were observed [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 ascribed to the chemical effect of fumed silica on the water/gypsum reaction, which strengthens the interior bonds between gypsum crystals.

Previous studies [12, 61] have also been performed to evaluate the effectiveness of incorporating alumina fillers into dental plaster. The findings exhibited that the compressive strength and surface hardness of plaster composites were raised from 7.8 to 70 MPa and from 64.4 to 124.3, respectively, whereas the setting expansion was shortened 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 led to a decrease in the production of dihydrate crystals, thereby reducing the generation of internal porosity. Different fillers have also been employed to modify the gypsum materials. As a result of that, improved flexural and compressive strength with decreased linear expansion were achieved [9]. White Portland cement was also introduced as an additive for reinforcing the gypsum plaster [62]. The presence of white cement at an ideal ratio of 4.0% w/w was found to support other significant properties, such as compressive strength and setting time, in addition to mitigating the weak points of gypsum, including its relatively low hardness and water solubility.

From an ecological perspective, efforts have been made to study how adding certain waste materials as fillers, such as blast furnace slag, unburnt rice husk, and calcium carbonate, affects 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 product generated from the cutting processes of marble blocks. The physical properties, such as density and flowability, of gypsum composites were significantly improved.

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)
Fumed silica	0.6, 1.2	Local gypsum (Juss)	0.3 – 0.4	Decreasing density and compressive strength. Higher porosity level.	(25)
Glass fibres	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 fibres	0.2, 0.4	Plaster	0.5 – 0.6	Fibre 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

The reality is that reinforced gypsum materials have a future in producing low-cost materials and innovative product development. Currently, numerous attempts have been carried out to improve the gypsum properties and explore the gypsum behaviour after filler inclusion. Furthermore, further studies are required to investigate the potential interaction between the reinforcing agents and the gypsum matrix. Filler treatment and reactivity could play an important role in raising the composites' performance [64]. Selection of the efficient filler type, size, and form could also be other promoting factors leading to enhancing the performance of the resultant gypsum composites. Although the application of strengthening dental gypsum by impregnating several types of additives is quite limited, this technique could be the method of choice for developing gypsum products.

Conclusions

The gypsum dehydration enhanced the surface characteristics of gypsum and reduced the time required at the dental laboratory, but detrimental effects on mechanical attributes have been observed. Although dental gypsum can be modified by using different types of mixing water and disinfectants, unstable performance and inferior mechanical characteristics were reported. However, encouraging outcomes have been presented by the inclusion of several types of ceramic fillers. Enhancing the plaster characteristics will lead to reducing stone employment and lower the cost. Although the use of this technique could play an important role in improving the behaviour 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 Desulfurisation

W/P ratio Water-to-Powder ratio

MPa Megapascal (unit of compressive strength)

MHz Megahertz (microwave frequency unit)

ADA American Dental Association

w/w Weight by weight (concentration ratio)

W Watt (the standard unit of power)

Author Contributions

NWE; data collection, drawing the figures, and writing the first draft. FK ; study conception and design. MMA; review and editing of the manuscript. ZAA; supervision and leadership role in the planning and implementation of the research activity. The final version of the manuscript was reviewed and approved by all authors for publication.

Conflicts of Interest

The authors have disclosed no conflicts of interest.

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