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# Physical properties of dental plaster filled with marble powder: a pilot study

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## Abstract

**Background:** Gypsum materials are frequently utilized in dental technology. Dental plaster is one of these products that is mainly used to produce dental casts and mounting purposes. Although the cost of dental plaster is very low, their inferior compressive strength, low abrasion resistance and dimensional instability restricted their usage as primary and working casts. The inclusion of different fillers in gypsum products could play an important role in improving their performance.

**Aim:** The aim of this study was to evaluate the physical properties of dental plaster incorporated with various concentrations of Marble powder (MP).

**Methodology:** Gypsum composites were prepared by incorporating 1.0, 3.0, 6.0 and 9.0 wt.% of MP. The neat plaster/mixture comprised the control group. The prepared gypsum composites samples were characterized in comparison with the control group. The density, porosity and fluidity of dental MP/plaster samples were investigated. The correlation between density and fluidity was also conducted.

**Results:** The gypsum composite samples displayed a higher density of 47% than the control group. However, a remarkable decrease in porosity level was observed as MP content increased. Significant improvements in the fluidity of the dental plaster after impregnating MP filler ($p<0.05$) whereas there is no significant correlation between density and fluidity of gypsum composites ($p>0.05$).

**Conclusion:** The concentration of MP in dental plaster is proportional to the density and fluidity of the material and inversely proportional to its porosity.

**Keywords:** Dental gypsum, Fluidity, Porosity, Marble powder.

## 1. Introduction

Gypsum products are one of the most important substances utilized in dental technology. Duplication of the patient's mouth is frequently performed by generating gypsum casts to facilitate treatment planning, documentation, and construction of prosthodontic restorations [1]. As stated by American Dental Association (ADA), gypsum products are categorized into five different types: impression plaster (type I), dental plaster (type II), dental stone (type III), high-strength dental stone (type IV), and high-strength and high expansion dental stone (type V). These materials have a similar chemical composition ($CaSO_4.1/2\,H_2O$), but mechanical and physical characteristics differ due to differences in particle shape, size, and porosity [2, 3].

Dental plaster exhibits low strength, poor dimensional stability, and lower cost compared to other gypsum products [4]. This material is employed to generate study casts for diagnosing and designing the restorations. The working cast should be made from a material that exhibits high strength, better surface hardness, low porosity, and good dimensional stability [1]. Such characteristics are prerequisites for promoting the material's ability to resist carving force and scratching, as well as inferior compressive strength [3]. Therefore, developing plaster with enhanced properties to substitute existing traditional material is required. The addition of various additives to gypsum products could play an important role in improving their performance. A previous work [5] reported that the compressive strength of plaster material is remarkably enhanced by impregnating chopped carbon fibres. Hamdy et al. [1] found that adding 10% nano alumina to dental plaster enhanced the surface hardness and compressive strength significantly. Furthermore, nano silica impregnation resulted in increased surface hardness and decreased surface roughness, with no change in compressive strength [6, 7]. As a result, integrating fillers and nanoparticles into dental gypsums can improve their performance, which provided an excellent reference for the clinical preparation of high-precision dental prostheses [8].

Marble powder (MP), as a class of ceramic material, consists mainly of calcium carbonate ($CaCO_3$), with several other oxides [9]. This material could be used as a filler for producing gypsum composites. MP is obtained as waste material during the mining or cutting process of marble stone. According to one estimate, 25% of handled marble turns into powder [10]. These by-products are found in the environment and contribute to pollution [11, 12]. The usage of MP decreases the cost of the production of gypsum material and reduces the costs of eliminating it from the environment [13]. The behavior of polymer composites reinforced with waste MP was investigated in recent works [9, 12]. The polymer composite materials with increased qualities have been postulated, while the reprocessing of MP is expected to reduce construction production costs.

Polymer composites filled with MP were reported to have increased compressive strength, impact strength, and surface hardness by numerous studies [10, 14]. In the present work, MP was introduced as a new dental filler as its use has not been documented in dental literature according to the authors' knowledge. Therefore, the present work aimed to prepare dental gypsum composites loaded with various concentrations of waste MP and investigated their effect on physical properties such as density, porosity, and fluidity.

## 2. Materials and methods

The various MP and dental plaster ratios used for sample preparation are shown in Table 1. The traditional dental plaster samples (control) were fabricated by blending dental gypsum (Dental plaster, type II) with water with a ratio of 0.5 [4]. Gypsum powder is weighed and manually mixed with measured water using a rounded blade spatula in a rubber bowl as per the manufacturer's recommendations to reach a homogeneous and smooth mixture, preventing conceivable air bubbles. During the mixing, the bowl was jolted to facilitate wetting and escape of entrapped air. Then, the mixture was poured into plastic molds laid on a vibrator (Degussa Vibrator, R2, Germany).

**Table 1. Formulation of the samples employed in the current study**

| Formulation | Plaster (g) | MP (g) | Water (ml) |
|---|---|---|---|
| Unmodified Plaster | 100 | 0 | 50 |
| 1.0 wt% MP/plaster | 99 | 1 | 50 |
| 3.0 wt% MP/plaster | 97 | 3 | 50 |
| 6.0 wt% MP/plaster | 94 | 6 | 50 |
| 9.0 wt% MP/plaster | 91 | 9 | 50 |

For dental plaster composite groups, MP (Figure 1) was placed in an oven at 40±2°C for 24 hours to avoid any potential moisture. Then, the dried MP was manually incorporated into the conventional dental plaster powder before water mixing. Four concentrations (1.0, 3.0, 6.0, 9.0 wt.%) of MP filler were prepared and investigated [14]. The mixing procedures were repeated as performed with the control group.

### 2.1. Density determination

Cylinder-shaped samples (25×30 mm, diameter and high, respectively; Figure 2) of each ratio of dental plaster were made utilizing plastic containers at ambient temperature. The samples were ejected from the container after 30 min from the beginning of blending. The samples were then weighed with a digital balance (ME204E, Mettler Toledo, USA) and considered as a reference. An hour after the blending commenced, the specimen weights were taken once more. The samples density was determined by the weight of the sample divided by the volume of the sample. A digital calliper was used to measure the exact dimensions (length and diameter) of the samples. Five samples were prepared and examined for each concentration.

### 2.2. Porosity assessment

Samples used in density evaluation were employed for porosity determination. The weight of each sample was taken in air and water. The samples were soaked in water until a constant weight is reached. Five specimens for each formulation were decided to compute the porosity percent using the following equation [15]:

$$P = \frac{W_a - W_d}{W_a - W_w} \times 100 \qquad (1)$$

Where: P is apparent porosity; $W_a$ denotes the weight of the saturated sample (g) in air, $W_d$ represents the weight of the sample (g) before water immersion, $W_w$ indicates specimen weight (g) in water.

### 2.3. Fluidity determination

The fluidity test was applied in accordance with ISO 6873. A tubular plastic container (35×50 mm, diameter, and height, respectively) was positioned on a glass plate. The mixture was poured into the mold until the blended plaster settled down and flushed from the mold. After that, the container was slowly raised upright from the plate allowing the mixture to extend over the glass plate. The major and minor diameters of the plaster samples were recorded after one minute of elevating the mold. Fluidity was measured after one minute from the beginning of blending. The mean of the diameters was set as the samples' fluidity. Five samples were made and tested for each ratio.

### 2.4. Statistical analysis

The obtained data were subjected to statistical analysis using SPSS version 22. The one-way analysis of variance (ANOVA) was applied to determine the differences among the examined groups followed by Tukey's *post hoc* test. The statistical significance was considered at $p < 0.05$.

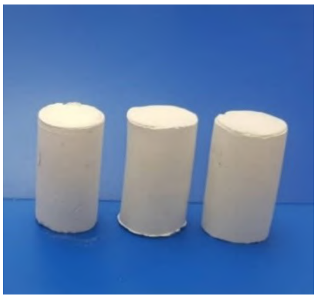

Figure 1. Marble powder (MP) used in sample preparation.
Figure 2. Gypsum samples used in this study

## 3. Results

The densities of unmodified dental plaster and MP/plaster composites are shown in Table 2. The modified gypsum composites exhibited greater density than the unmodified plaster ($p$<0.001). The post hoc test for the density values is presented in Table 3. For the MP/plaster composites, the density of the modified plaster is directly increased as the MP content is raised. In the highest level of MP, the density was enhanced by 47%.

**Table 2. Effect of MP content on the density of the dental plaster composites compared with the neat dental plaster**

| Formulations | *n* | Density ($\rho_c$) (g/cm³) | Increase in density (%) | *p* |
|---|---|---|---|---|
| Unmodified plaster | 5 | 0.95 ± 0.08 | 0 | - |
| Plaster + MP 1.0wt.% | 5 | 1.13 ± 0.05 | 19 | 0.001 |
| Plaster + MP 3.0wt.% | 5 | 1.28 ± 0.06 | 35 | <0.001 |
| Plaster + MP 6.0wt.% | 5 | 1.35 ± 0.04 | 42 | <0.001 |
| Plaster + MP 9.0wt.% | 5 | 1.4 ± 0.03 | 47 | <0.001 |

The porosity level of the experimented materials was presented in Figure 3. The porosity was decreased with an increase in the MP concentration. unmodified dental plaster revealed the highest porosity 22.9±3.07%, whereas MP/plaster composites exhibited lower porosity percentages; 20.4±2.88 % ($p$>0.05), 19.6±2.14 % ($p$>0.05), 18.7±1.25 % ($p$>0.05) and 16.5±1.59 % ($p$<0.05) at various MP filler loadings; 1.0, 3.0, 6.0 and 9.0 wt.% respectively. The porosity is significantly decreased by 39% at the highest ratio of MP ($p$=0.002). Statistical analysis of porosity data was depicted in Table 4.

The fluidity data of the dental plaster materials were presented in Figure 4. The results showed statistically significant differences in fluidity among the tested dental plaster groups ($p$<0.05). The fluidities of the experimented plaster samples were 41.1±0.79 mm, 41.81±1.45 mm ($p$>0.05), 42.58±0.73 mm ($p$>0.05), 45.05±2.12 mm ($p$<0.001) and 46.26±1.68 mm ($p$<0.05) when 0.0, 1.0, 3.0, 6.0 and 9.0 wt.% of MP were incorporated respectively. The fluidities comparison results between the unmodified and modified dental plaster were displayed in Table 5. The relationships between density and fluidity of gypsum materials are shown in Figure 5. Statistically, there was an insignificant correlation between density and fluidity of gypsum composites ($p$>0.05).

**Table 3. Post hoc analysis for the comparison of densities of the tested dental plaster samples**

| Materials | | Mean Difference | Std. error | *p*-value | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| Unmodified Plaster | Plaster + 1.0%MP | 0.16000* | 0.03393 | 0.001 | 0.2615 | 0.0585 |
| | Plaster + 3.0%MP | 0.30600* | 0.03393 | <0.001 | 0.4075 | 0.2045 |
| | Plaster + 6.0%MP | 0.37600* | 0.03393 | <0.001 | 0.4775 | 0.2745 |
| | Plaster + 9.0%MP | 0.42200* | 0.03393 | <0.001 | 0.5235 | 0.3205 |

* The mean difference is significant at the 0.05 level.

**Table 4. Post hoc analysis for the comparison of porosity levels between the unmodified and modified dental plasters**

| Materials | | Mean Difference | Std. error | *p*-value | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| Unmodified Plaster | Plaster + 1.0%MP | 2.50000 | 1.45437 | 0.445 | 1.8520 | 6.8520 |
| | Plaster + 3.0%MP | 3.30000 | 1.45437 | 0.196 | 1.0520 | 7.6520 |
| | Plaster + 6.0%MP | 4.20000 | 1.45437 | 0.062 | 0.1520 | 8.5520 |
| | Plaster + 9.0%MP | 6.40000* | 1.45437 | 0.002 | 2.0480 | 10.7520 |

* The mean difference is significant at the 0.05 level.

**Table 5. Post hoc analysis for the comparison of fluidity between the unmodified and modified dental plasters**

| Materials | | Mean Difference | Std. error | *p*-value | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| Unmodified Plaster | Plaster + 1.0%MP | 0.70800 | 0.91867 | 0.936 | 3.4570 | 2.0410 |
| | Plaster + 3.0%MP | 1.67000 | 0.91867 | 0.391 | 4.4190 | 1.0790 |
| | Plaster + 6.0%MP | 3.95000* | 0.91867 | 0.003 | 6.6990 | 1.2010 |
| | Plaster + 9.0%MP | 5.15000* | 0.91867 | 0.000 | 7.8990 | 2.4010 |

* The mean difference is significant at the 0.05 level.

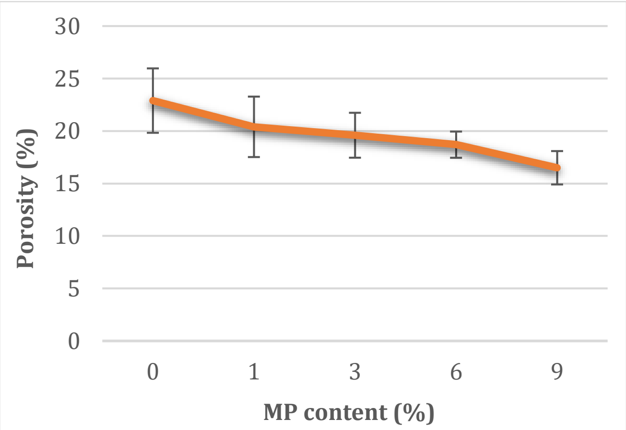


Figure 3. Porosities of unmodified plaster and plaster composites.

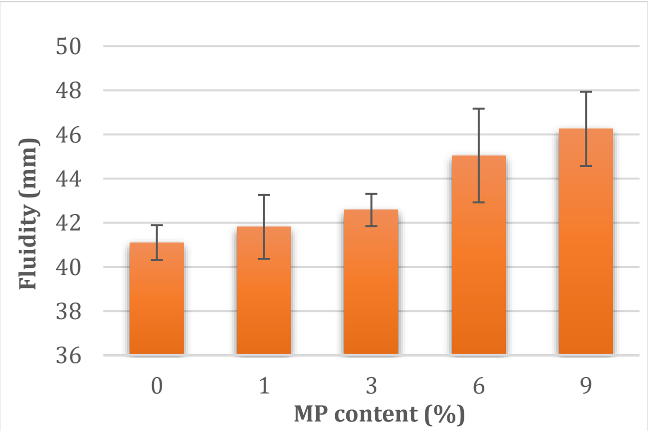


Figure 4. Effect of filler content on the fluidity of MP/plaster composites.

## 4. Discussion

### 4.1. Density evaluation

Density is a critical physical property of dental gypsum materials. During the setting, gypsum materials undergo dimensional alternations. These changes could mostly be due to an increase in the number and size of gypsum crystals. As a result, crystals entanglements occur and propel as opposed to each other, leading to an "outward thrust action". The crystals would conquer a greater site volume, thus producing an expansion. Furthermore, the outward thrust action generates internal porosities in the set material [16]. The improvement in density could be attributed to the presence of the high density of the filler (i.e., 2.69 g/cm$^3$) in the gypsum materials. Furthermore, the MP particles would reduce the gaps among the gypsum grains thus improving the strength [17]. This finding was in agreement with the previous outcomes that the density of gypsum composites was linearly related to the increase in filler level. The additive particles tend to fill the interstitial gaps between the gypsum grains leading to the increase in the weight without increasing the volume, thus increasing the bulk density [18]. Therefore, the Production of more dense plaster composites could lead to improvements in mechanical properties [19]. Aljbouri *et al.* [6] reported that the small-sized filler particles and their great surface area result in decreasing surface tension, and improving the wettability of dental gypsum to the water. The solubility rate of the dental gypsum will be raised, consequently, a higher rate of crystallization will take place. Therefore, the porosity of dental gypsum reduces, thereby constraining the cracking propagation and dimensional alternations in the dental gypsum cast, which enhances the hardness and the dimensional alterations.

### 4.2. Porosity

The mechanical properties of the gypsum products depend on the number of porosities in the mass. The more the porosities the weaker will be the structures. In the present study, unmodified plaster showed the highest level of porosities compared to modified groups (Figure 3). This behavior could be due to the irregular forms of the plaster particles, which inhibit them to fit firmly [20]. In addition, the incorporation of MP considerably decreased the porosity of gypsum composites, which exerted a favourable influence on the characteristics of the resultant gypsum materials. This outcome was in agreement with the density data of the experimented samples. For dental plaster, it was assumed that higher density is escorted by less porosity [17, 18]. Similar findings were observed by Khalil AA *et al.* [21], who found that the porosity of the neat plaster is reduced by impregnating rice husk filler. This behavior was attributed to sealing the interstices among the plaster grains by the added filler, thus lowering the pores.

### 4.3. Fluidity

The plaster mix should exhibit adequate flow to reproduce the complete details of the impression accurately. In the present study, a considerable increase in fluidity was observed as the content of MP is raised (Figure 4), and this behavior could be attributed to reducing the plaster content as the MP ratios are increased with a stable amount of water in the gypsum composites. The inclusion of the fillers causes a reduction of the gypsum level, therefore, less amount of water is needed [19]. The reduction in plaster amount could lead to lowering the reactivity of MP/plaster samples to water compared to unmodified plaster samples, thereby increasing the fluidity. In other words, 9.0% reduced the gypsum concentration to be 91% instead of 100%, which requires about 45 ml of water as fluidity for gypsum composite material rather than 50%. Consequently, the filler would lead to a slight increase in the fluidity of the composite due to the progressive amount of water applied for wetting the particles of the impregnated filler. The variation between the established consistency (50%) and the estimated level of water for consistency (45%) will remain free in the composite materials to be utilized for wetting the filler particles [21]. Higher concentrations of the filler gradually improved the fluidity of the resultant composite materials. These outcomes were in agreement with the finding of a previous work which concluded that the greater reactivity of stone powder to water could result in decreasing fluidity of the stone mixture [17]. Rajab et al. [22] reported that the excessive water content, the long time for saturating the solution due to fewer nuclei of crystallization. Furthermore, it is well-known that alterations in the W/P ratios have a significant impact on the physical and mechanical properties of gypsum materials [18, 22, 23].

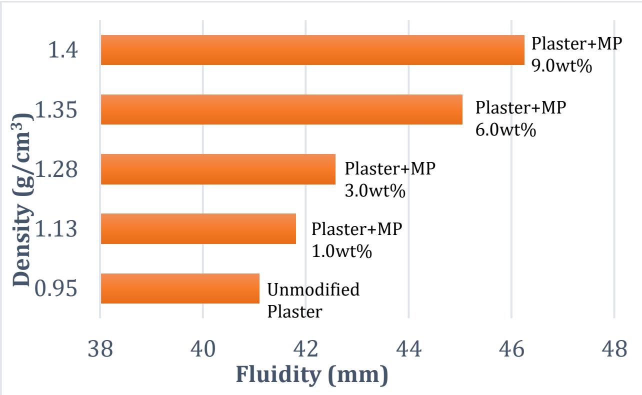


Figure 5. Correlation between density and fluidity

### 4.4. Correlation between density and fluidity

As the density affects the mechanical properties, it could be correlated to other attributes such as fluidity. There was little information on gypsum fluidity and the effect of fillers on it. Figure 5 shows that when the filler amount increased, both properties improved noticeably. Despite the fact that the increased density of MP/plaster composites was attributed to the dense nature of the filler, the subsequent reduction in plaster content resulted in excellent fluidity despite the absence of an explicit MP effect. This indicates that there was no contact or bonding between MP and the plaster/water mixture, as well as a higher water/plaster ratio [6]. This behavior is in agreement with the hygroscopic attribute of dental gypsum, where excessive water requires sufficient surface tension to pull the crystals together [23]. Khalil *et al.*, [21] on the other hand, found that the impregnation of ceramic or polymer additives reduced the fluidity of gypsum composites. This reduction can be due to their tiny particles functioning as a plasticizer, increasing the plasticity of the resulting paste and therefore lowering the amount of water needed to wet any of them. As a result, the kind of impregnated additives would have the greatest impact on such a relationship.

## 5. Conclusion

The application of MP as a filler in dental gypsum composites was investigated in this pilot study. The modified plaster was successfully prepared using various filler ratios. As the MP content was increased, the density and fluidity improved. Lower porosity levels, on the other hand, were found to increase MP ratios. Such findings suggest that more research into the mechanical characteristics, setting time, and expansion of MP/gypsum composites should be conducted.

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