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Evaluation of the Reusability of Dental Stone Powder After Crushing and Rehydration: An In Vitro Mechanical Study

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Abstract

Aim: This study aimed to evaluate the effect of recycling type III dental stone powder through crushing and rehydration on surface hardness, compressive strength, surface roughness, and setting time compared with conventional dental stone.

Materials and Methods: Eighty specimens of type III dental stone were fabricated and divided according to the performed tests into control and recycled groups. Before recycling, the previously set dental stone specimens were disinfected using 0.525% sodium hypochlorite solution, then crushed, dried at 100°C for one hour, and remixed using the same powder-to-water ratio as the conventional material. Surface hardness was measured using a Shore D hardness tester, surface roughness was assessed using a digital profilometer, and setting time was evaluated using a standardized penetration method. Data were analyzed using descriptive statistics and one-way ANOVA with a significance level of $p \leq 0.05$.

Results: The control group showed slightly higher surface hardness values than the recycled group; however, the difference was statistically non-significant ($p = 0.111$). The recycled group's mean compressive strength was 23.91 ± 1.88 MPa, while the control groups was 24.85 ± 1.72 MPa. At $p = 0.274$, the difference was not statistically significant ($p = 0.274$). The recycled group had considerably greater surface roughness values ($p = 0.004$). Additionally, recycled dental stone showed a little longer setting time, although the difference was not statistically significant ($p = 0.146$).

Conclusion: Recycling dental stone resulted in a slight non-significant reduction in surface hardness and compressive strength, a significant increase in surface roughness, and a slight non-significant increase in setting time. The recycled material retained satisfactory mechanical qualities in spite of these

modifications, indicating its possible application as a cost-effective and sustainable substitute in dental labs.

Keywords: Recycled dental stone; gypsum recycling; type III dental stone; surface roughness; sustainable dentistry.

Introduction

Because gypsum products can replicate oral tissues with acceptable dimensional accuracy and mechanical qualities, they are among the most commonly used materials in prosthodontics and restorative dentistry [1]. Study casts, working models, removable prostheses, orthodontic models, and diagnostic records are frequently made using dental stone. Because type III dental stone offers an appropriate balance between strength, precision, and handling features, it is especially used in prosthodontic treatments [2].

The use of gypsum materials in dental laboratories and educational institutions has significantly increased due to the growing need for dental care. Consequently, a significant amount of discarded dental casts are produced every day. Despite their potential for recycling and their influence on the environment, the majority of these items are disposed of as ordinary solid waste [3].

Globally, healthcare systems are increasingly concerned about environmental sustainability. By discarding impression materials, gypsum products, plastics, metals, and chemical disinfectants, dentistry contributes to environmental contamination [4].

Reducing waste production and promoting recycling practices whenever feasible are key components of contemporary sustainable dentistry approaches. Therefore, recycling dental stone materials may help reduce laboratory waste and the cost of continuously using new gypsum products [5].

The primary ingredient in gypsum products is calcium sulfate hemihydrate, which during the setting process combines with water to generate calcium sulfate dihydrate crystals. The creation and interlocking of these crystals have a significant impact on the material's final mechanical characteristics [6]. The strength and surface properties of recycled gypsum products may be affected by changes in crystal shape, porosity, particle size, or water absorption.

Gypsum recycling techniques have been successfully implemented in a number of industrial sectors. To create reusable dental stone powder, recycling processes in dentistry often entail crushing previously set casts into a fine powder, drying or heating the material, and remixing it with water [7]. Concerns about how recycling affects the material's mechanical and physical qualities still exist, though.

One of the most crucial features of dental stone is its surface hardness, which determines how resistant it is to abrasion and scratching during laboratory processes including wax-up, cutting, flasking, and finishing [8]. Diminished hardness may have a detrimental impact on the quality of prosthetic restorations and dental cast dimensional accuracy.

Another important mechanical characteristic of dental stone is its compressive strength, which indicates the material's resistance to functional and laboratory loads. During prosthodontic procedures, enough compressive strength is crucial to preventing cast distortion and breakage. This characteristic may be impacted by changes in porosity and crystal structure brought on by recycling [9].

Surface roughness is also considered a clinically important property because rough surfaces may interfere with the adaptation and accuracy of dental prostheses. Surface texture is influenced by several factors including powder particle size, mixing technique, water-to-powder ratio, setting reaction, and crystal arrangement [9].

Setting time is another important property because it directly affects laboratory efficiency and handling procedures. Excessively prolonged setting time may delay laboratory work, whereas rapid setting may reduce working time and compromise manipulation procedures [10].

Infection control measures are essential in prosthodontic practice because dental casts may become contaminated during clinical and laboratory procedures. Dental impressions and casts can carry microorganisms capable of transmitting infection between patients, clinicians, and laboratory personnel [11]. Therefore, disinfection of dental casts is considered a routine procedure in many dental laboratories.

Sodium hypochlorite is one of the most commonly used disinfectants in dentistry because of its broad antimicrobial activity, low cost, and availability [12]. Previous investigations demonstrated that sodium hypochlorite may influence some physical properties of gypsum materials depending on concentration and exposure time [13]. Nevertheless, limited studies evaluated the effect of recycling disinfected dental stone materials after crushing and rehydration.

Recent studies emphasized the importance of evaluating modifications and disinfection procedures associated with dental stone materials and prosthodontic laboratory techniques [14,15]. Additional investigations highlighted the importance of maintaining surface quality and dimensional stability during laboratory procedures [16].

Despite increasing interest in sustainable dentistry, limited information is available regarding the effect of recycling disinfected type III dental stone on hardness, surface roughness, and setting time. Therefore, the present study aimed to evaluate the feasibility of recycling disinfected type III dental stone powder through crushing and rehydration and to investigate its effect on surface hardness, compressive strength, surface roughness, and setting time compared with conventional dental stone.

Materials and Methods

Study Design

This in vitro experimental study was conducted to evaluate the influence of recycling disinfected type III dental stone powder on surface hardness, surface roughness, and setting time.

Materials Used

Type III dental stone (Elite Model, Zhermack, Italy) was used throughout the present investigation. Sodium hypochlorite solution (0.525%) was utilized as the disinfecting agent before recycling procedures. A Shore D hardness tester was used to assess surface hardness, and a digital profilometer with a diamond stylus was used to quantify surface roughness.

Sample Size and Grouping

ADA Specification No. 25 was followed in the fabrication of a total of eighty specimens. Three testing categories were created from the specimens:

- Surface hardness test: 20 specimens
- Compressive strength: 20 specimens
- Surface roughness test: 20 specimens
- Setting time test: 20 specimens

Each testing category was further subdivided into:

- Control group (10 specimens)
- Recycled group (10 specimens)

Preparation of Control Specimens

Fresh type III dental stone powder was mixed in accordance with the manufacturer's instructions to create the control specimens. A rubber mixing bowl and stainless-steel spatula were used to combine 100 grams of powder with 30 milliliters of distilled water until a uniform mixture was achieved.

The resulting mixture was poured into silicone molds using a mechanical vibrator to reduce air bubble formation and promote surface adaptability. A glass slab was put over the mold surface to achieve parallel and even specimen surfaces.

Preparation of Recycled Specimens

Previously set dental stone casts were first disinfected using 0.525% sodium hypochlorite spray. The disinfectant was used until the entire surface was saturated. To keep the specimens in contact with the disinfectant, paper towels dampened with the solution were used to wrap them.

Following disinfecting, a metal file was used to physically crush the casts into a fine powder. To eliminate any remaining moisture and enable powder reuse, the resulting powder was dried in an electric oven at 100°C for an hour. The recycled powder was combined with distilled water using the same powder-to-water ratio as the control material after it had dried.

The recycled mixtures were poured into silicone molds using a mechanical vibrator under the same laboratory conditions used for the control specimens.

Surface Hardness Test

Surface hardness was evaluated using a Shore D hardness tester (TIME Group Inc., Beijing, China). The indenter tip was placed perpendicular to the specimen surface until penetration occurred. Five readings were obtained from different locations on each specimen, and the mean value was calculated.

Compressive Strength Test

A universal testing apparatus (Shimadzu AG-X Plus, Kyoto, Japan) was used to assess compressive strength. Before testing, twenty cylindrical specimens were made and kept in storage for a full day. Up until fracture, each specimen was compressed at a crosshead speed of 1 mm/min. Compressive strength values, given in MPa, were obtained by recording the highest fracture load.

Surface Roughness Test

Surface roughness measurements were performed using a digital profilometer (TIME Group Inc., Beijing, China). The diamond stylus traversed the specimen surface in a straight line, and three readings were obtained from different regions of each sample. The average value was recorded for statistical analysis.

Setting Time Test

Setting time was evaluated using a standardized penetration method. The elapsed time from the beginning of mixing until the material reached final set was recorded in minutes using a digital stopwatch (Casio Inc., Tokyo, Japan).

Statistical Analysis

The collected data were analyzed using Statistical Package for Social Sciences (SPSS) software version 25. Descriptive statistics including mean and standard deviation were calculated. One-way ANOVA was used to determine statistically significant differences between the groups. Statistical significance was considered at $p \leq 0.05$.

Results

Surface Hardness

The control group demonstrated a mean surface hardness value of 82.51 ± 1.53, whereas the recycled group demonstrated a mean value of 81.33 ± 1.62. Statistical analysis revealed no statistically significant difference between the groups ($p = 0.111$). As presented in Table 1.

The recycled specimens demonstrated a slight reduction in hardness compared with conventional dental stone; however, the reduction was minimal and statistically non-significant as illustrated in Figure 1.

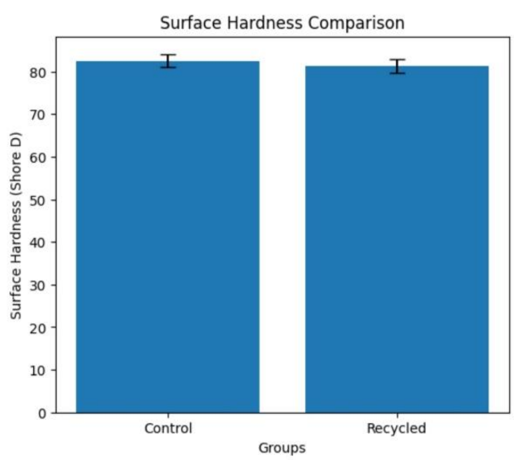

Figure 1. Comparison of mean surface hardness values between control and recycled type III dental stone groups.

Compressive Strength

The control group demonstrated a mean compressive strength value of 24.85 ± 1.72 MPa, whereas the recycled group demonstrated a mean value of 23.91 ± 1.88 MPa. Statistical analysis revealed no statistically significant difference between the groups ($p = 0.274$). As presented in Table 2.

The recycled specimens demonstrated a slight reduction in compressive strength compared with conventional dental stone; however, the reduction was statistically non-significant as illustrated in Figure 2.

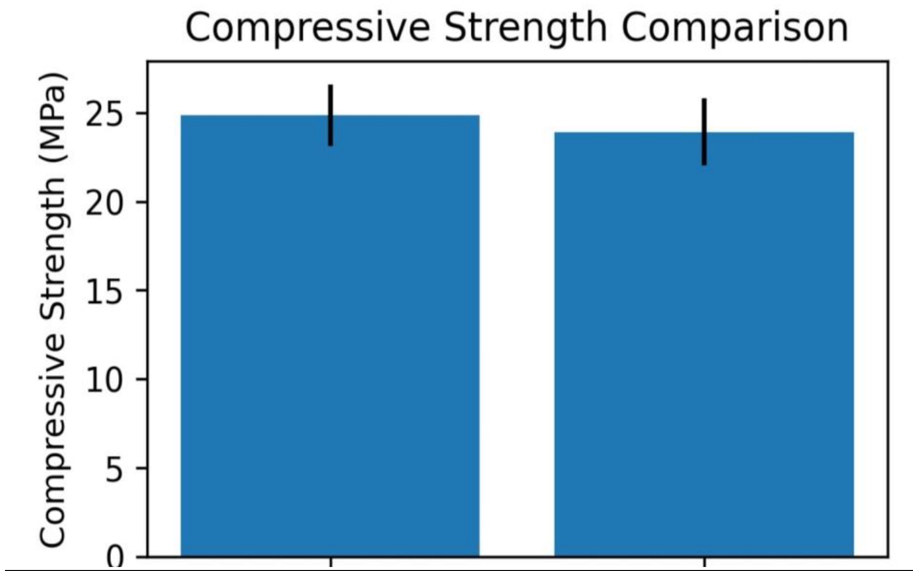

Figure 2. Comparison of mean compressive strength values between control and recycled type III dental stone groups.

Surface Roughness

The control group demonstrated a mean surface roughness value of 1.21 ± 0.05 µm, while the recycled group demonstrated a mean value of 1.29 ± 0.06 µm. Statistical analysis showed a significant difference between groups ($p = 0.004$). As presented in Table 3.

The recycled group demonstrated significantly greater surface roughness compared with the conventional material as illustrated in Figure 3.

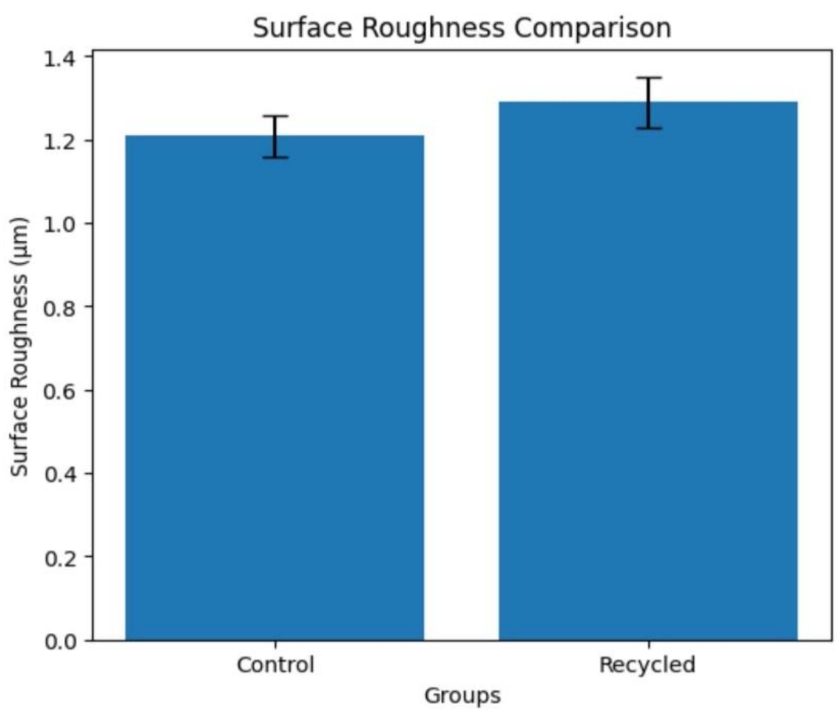

Figure 3. Comparison of mean surface roughness values between control and recycled type III dental stone groups.

Setting Time

The recycled dental stone demonstrated a slightly longer mean setting time compared with the control group. However, the difference between groups was statistically non-significant ($p = 0.146$). As presented in Table 4.

Although recycled dental stone demonstrated a slight increase in setting time as illustrated in Figure 4, the values remained within clinically acceptable limits.

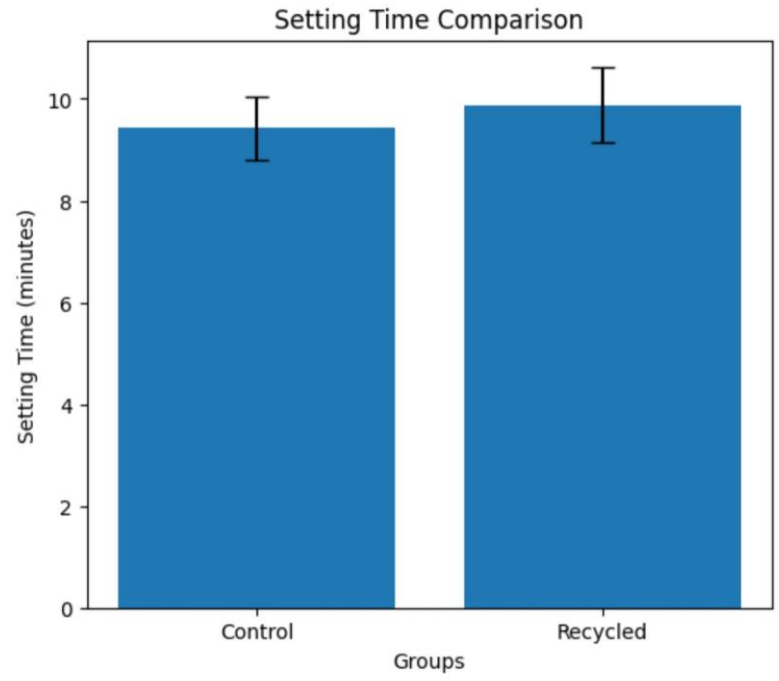

Figure 4. Comparison of mean setting time values between control and recycled type III dental stone groups.

Discussion

The present study evaluated the feasibility of recycling disinfected type III dental stone powder after crushing and rehydration and investigated its effect on surface hardness, surface roughness, and setting time.

The results demonstrated that recycled dental stone maintained acceptable mechanical properties despite slight alterations in tested characteristics. Surface hardness demonstrated a slight reduction in the recycled group; however, the difference was statistically non-significant.

The reduction in hardness may be attributed to changes in crystal morphology and increased porosity associated with the recycling process. During gypsum setting, calcium sulfate hemihydrate reacts with water to form interlocking calcium sulfate dihydrate crystals. The efficiency of crystal interlocking largely determines the final mechanical properties of the material [17].

Particle morphology may change and crystals' capacity to rearrange effectively during the second setting reaction may be diminished by crushing and reheating previously set gypsum. According to earlier research, recycled gypsum may show altered crystal structure and increased porosity, which could affect mechanical behavior [18].

However, the current results showed that the hardness decrease was negligible and not statistically significant. This suggests that during laboratory manipulation, recycled type III dental stone might nevertheless offer a respectable level of abrasion resistance.

These findings are consistent with previous investigations evaluating modifications of gypsum materials. Hameed and Al-Dohan reported that certain additives produced only limited changes in the surface hardness of type III dental stone [19].

Similar findings were reported by Bilguun, who demonstrated that recycled gypsum retained acceptable mechanical behavior despite slight alterations in physical properties [20].

The recycled group's compressive strength showed a minor decline, but the difference was not statistically significant.

Increased porosity and insufficient crystal interlocking following crushing, drying, and rehydration processes could be the cause of the decrease. However, the recycled material's acceptable compressive strength ratings indicate that recycling did not significantly reduce its capacity to support loads [20].

The recycled group showed a statistically significant increase in surface roughness. The uneven particle shape and changed crystal arrangement after crushing and reheating processes could be the cause of this increase.

Smooth crystal formation during setting may be hampered by irregularly shaped and sized particles that are produced during the grinding process. Increased surface roughness may also result from incomplete recrystallization and persistent porosity [21].

Water diffusion during the setting reaction may potentially be impacted by the increased porosity linked to recycled gypsum particles. The higher roughness seen in the recycled group could be explained by increased porosity, which could result in uneven crystal arrangement and decreased surface homogeneity. Previous studies assessing the impact of changed gypsum formulations on surface texture and mechanical behavior showed similar results.

Although the increase in roughness was statistically significant, the recorded values remained within clinically acceptable limits. Therefore, recycled dental stone may still be considered suitable for selected prosthodontic laboratory procedures.

Previous studies evaluating disinfected gypsum casts reported variable effects on surface roughness depending on disinfectant type and concentration [22]. Nassar et al. demonstrated that certain disinfection procedures may slightly influence surface texture without causing clinically unacceptable deterioration [23].

Regarding setting time, recycled dental stone demonstrated a slightly longer setting time compared with the control group. This finding may be related to delayed crystal nucleation and altered powder characteristics after recycling.

The slight increase in setting time observed in the recycled group may be clinically related to reduced reactivity of recycled calcium sulfate particles after repeated heating and drying procedures. Thermal treatment may alter the crystallization process and delay the formation of stable dihydrate crystals during the setting reaction.

The drying process may reduce the reactivity of some gypsum particles and slightly prolong the setting reaction. However, the observed increase in setting time was statistically non-significant and unlikely to create major laboratory difficulties.

Several recent studies emphasized the importance of sustainable dentistry and waste reduction in dental practice [24,25]. Recycling gypsum materials may contribute to reducing environmental pollution and minimizing the amount of laboratory waste generated during prosthodontic procedures.

In addition, recycling procedures may reduce the overall financial cost associated with repeated purchase of dental stone materials, particularly in educational institutions and high-volume dental laboratories. The reuse of gypsum products may therefore provide both environmental and economic advantages without producing major deterioration in material performance.

The present study also supports previous investigations published regarding the influence of modifications and disinfectants on dental materials and laboratory procedures .[14,16]

The findings of the current investigation may have practical implications for dental laboratories and educational institutions where large amounts of dental stone are routinely consumed. Recycling dental stone may reduce material costs and decrease environmental burden without causing major deterioration in mechanical performance.

From a clinical perspective, recycled dental stone may be useful for preliminary casts, diagnostic models, and selected laboratory procedures where minor alterations in surface properties are clinically acceptable. However, additional investigations are still required before recommending recycled gypsum materials for highly accurate definitive prosthodontic procedures.

Further studies are recommended to evaluate the effect of repeated recycling cycles on the physical and mechanical properties of dental stone materials.

Conclusion

In the present study, recycled type III dental stone demonstrated acceptable mechanical performance after disinfection, crushing, and rehydration. Surface hardness and compressive strength demonstrated a slight non-significant reduction, whereas surface roughness increased significantly. Setting time demonstrated a slight non-significant increase.

Despite these alterations, recycled dental stone maintained clinically acceptable properties, suggesting its potential use as a sustainable and economical alternative for selected dental laboratory procedures.

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Figure Legends:

Figure 1. Comparison of mean surface hardness values between control and recycled type III dental stone groups.

Figure 1. Comparison of mean compressive strength values between control and recycled type III dental stone groups.

Figure 3. Comparison of mean surface roughness values between control and recycled type III dental stone groups.

Figure 4. Comparison of mean setting time values between control and recycled type III dental stone groups.

Table Legends:

Table 1. Surface hardness values

Table 2. Compressive strength values

Table 3. Surface roughness values

Table 4. Setting time values

• **Ethics approval:** No need for ethics approval.

• **Competing interest:** Authors declare no conflict of interest.

• **Data availability:** Additional data will be made available on request.

• **Funding:** This article had no funding body.

Table 1. Surface hardness values

Group	Mean	SD	p-value
Control	82.51	1.53	
Recycled	81.33	1.62	0.111

Table 2. Compressive strength values

Group	Mean	SD	p-value
Control	24.85	1.72	
Recycled	23.91	1.88	0.274

Table 3. Surface roughness values

Group	Mean	SD	p-value
Control	1.21	0.05	
Recycled	1.29	0.06	0.004

Table 4. Setting time values

Group	Mean(min)	SD	p-value
Control	9.42	0.61	
Recycled	9.88	0.74	0.146