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COMPARISON OF THE SURFACE ROUGHNESS OF REFRACTORY CAST INVESTMENT MATERIAL BEFORE AND AFTER TREATMENT WITH WAX, HARDENING AGENTS- AN IN-VITRO STUDY

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ABSTRACT

Background: Achieving a smooth surface on refractory casts is essential for the accuracy and longevity of dental prostheses. Phosphate-bonded investment materials, although thermally stable, often exhibit surface roughness during wax pattern fabrication and processing.

Aim: To evaluate and compare the surface roughness of refractory cast investment material before and after treatment with hardening agents and subsequent heat treatment.

Materials and Methods: Twenty rectangular specimens were fabricated using commercially available phosphate-bonded investment material. Initial surface roughness was measured using a contact profilometer. Specimens were randomly divided into two groups (n=10): Group I treated with model hardener and Group II treated with beeswax. Surface roughness was re-evaluated after treatment. All specimens were then subjected to heat treatment at 875°C for 60 minutes, followed by gradual cooling, and final measurements were recorded. Statistical analysis was performed using Student’s t-test.

Results: A statistically significant reduction in surface roughness was observed in both groups after hardening and heat treatment ($p < 0.05$).

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Conclusion: Both hardening agents and heat treatment effectively reduced surface roughness of phosphate-bonded investment materials.

Keywords: Phosphate-bonded investment, surface roughness, refractory cast, model hardener, beeswax, heat treatment

1.INTRODUCTION

Investment casting is essential in restorative dentistry for fabricating indirect restorations such as crowns, bridges, and removable partial denture frameworks[1,2]. Investment materials are ceramic-based compounds used to form molds for casting dental alloys. An ideal material should accurately reproduce wax patterns while ensuring dimensional stability, surface smoothness, and strength[2]. However, their brittle nature makes them prone to surface deterioration during wax pattern fabrication, potentially affecting the accuracy of the final prosthesis[3,4]. Phosphate-bonded investments are widely preferred for high-melting alloys due to their superior thermal stability. In removable partial denture fabrication, refractory casts made from these materials must withstand high temperatures, yet they are susceptible to abrasion and loss of surface detail. To improve surface quality, refractory casts are treated with hardening agents or coatings such as waxes and chemical hardeners[4,5,6]. These agents penetrate and seal surface porosities, forming a smooth, dense, and abrasion-resistant layer that enhances durability and facilitates accurate waxing. The properties of phosphate-bonded investments are influenced by composition and heat treatment[5,7]. These materials achieve optimal strength and surface smoothness after thermal firing, typically between 800°C and 900°C. Excessive temperatures, particularly beyond 1375°C may lead to structural degradation and increased surface roughness, affecting casting accuracy[8].Hence, the purpose of this study was to compare and evaluate the surface roughness of phosphate bonded investment material before and after treatment with wax, hardening agents and after heat treatment around 875°C.

2. MATERIALS & METHODS

Preparation of wax block:

Modelling wax sheets were softened, cut to 5 × 2 cm, and layered to achieve 1 cm thickness. Layers were fused using a warm spatula, trimmed to obtain flat surfaces, finished on a warm glass slab and cooled in water.

Preparation of silicone mold: A PVS putty mold was made by mixing equal parts base and catalyst and pressing the wax block to form an index.

Preparation of specimens:

Twenty specimens were prepared by pouring vacuum-mixed phosphate-bonded investment (100 g powder:15 ml liquid) (6.75ml begosol + 8.25ml water) according to the manufacturer's instructions, into a PVS mold using a vibrator, then retrieved after 60 minutes and heat-dried at 220°C for 30 minutes to ensure drying and to drive off moisture to get the dense, smooth surface.

Pre-treatment surface roughness testing of investment specimens:

Specimens were numbered, cleaned, and a defect-free test surface was marked; surface roughness (Ra) was measured using a profilometer (Mitutoyo SJ-410) with a cut-off length of 0.8 mm, measuring force of 0.75 µm, and stylus tip angle of 60°, recording three readings per specimen and averaging them, after which the samples were divided into two equal groups based on the hardener used.

Grouping of specimens:

Total of 20 specimens were randomly divided into two groups.
Group I: 10 specimens (n=10) dipped in model hardener (specimens numbered from 1-10)
Group II: 10 specimens (n=10) dipped in bees wax (specimens numbered from 11-20)

Treating the specimens with hardening agents:
Hardening agents used were:
Model hardener
Bees wax

Group I: Specimens were immersed in model hardener for 10 seconds, removed, allowed to drain, and air-dried under controlled conditions.

Group II: Specimens were immersed in melted beeswax (61–66°C) for 15 seconds, removed, excess wax drained, and allowed to cool and solidify at room temperature.

Post-treatment testing: Surface roughness (Ra) was measured using a profilometer on different, non-overlapping areas to avoid stylus-induced scratches, and the mean of three readings per specimen was recorded.

Heat treatment: After hardening and initial testing, specimens were heated to 875°C, held for 60 minutes, and allowed to cool gradually in the furnace.

Post-heat testing: Surface roughness (Ra) was measured using a profilometer at three different locations per specimen, averaged, and compared with pre- and post-hardening values for statistical analysis.

FIG-1: Wax block

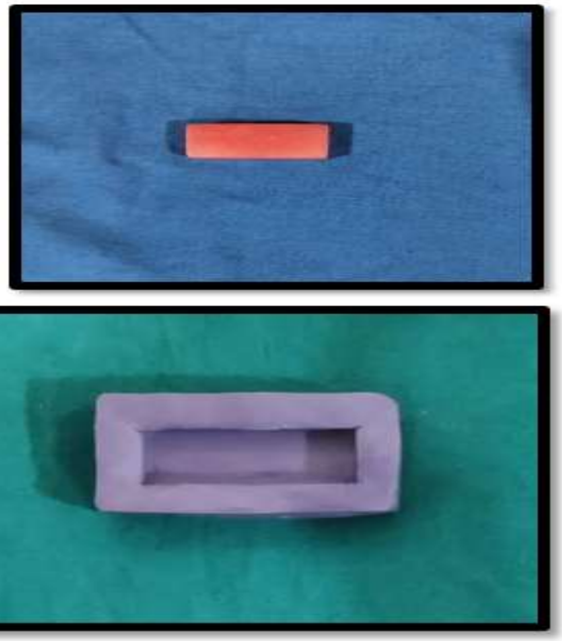

FIG-2:Silicone mold

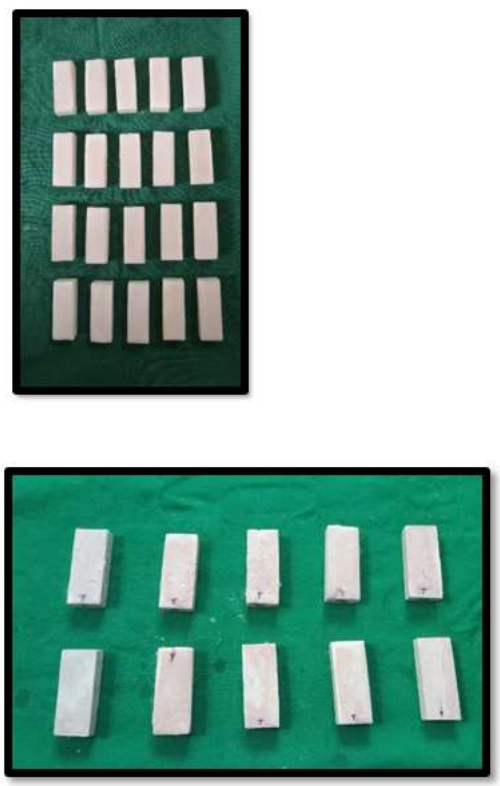

FIG-3: Specimens before dipping

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FIG-4: Specimens after dipping in hardener

FIG-5;Specimens after dipping in wax

FIG-6: specimens subjected to heat treatment

RESULTS

TABLE 1: Intergroup analysis of surface roughness of specimens before and after treatment with hardening agents.

Specimen no.	Before treatment		After hardening treatment		P -value	significance
	Mean	SD	Mean	SD		
Specimens 1-10	4.31	0.18	1.45	0.32	<0.001	Significant at p <0.01 level
Specimens 11-20	4.54	0.42	1.49	0.17	<0.001	Significant at p <0.01 level

Paired t-test analysis showed a significant reduction in mean surface roughness in both Group I (model hardener) and Group II (beeswax) after treatment compared to baseline ($p < 0.001$).

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TABLE-2: Comparison of mean surface roughness difference before and after surface treatment between the two specimen groups.

Treatment type	Before-after difference		p-value	Significance
	Mean	SD		
Hardener- treated (group 1)	2.86	0.29		
Wax-treated (group 2)	3.04	0.43	0.29	NS

An unpaired t-test showed no significant difference in the mean change in surface roughness between the two groups before and after surface treatment (p = 0.29).

TABLE-3: Intergroup analysis of surface roughness of specimens made of phosphate bonded investment material before treatment, after treatment with hardening agents and after heat treatment.

Test Conditions	Specimens 1-10		Specimens 11-20		p-value	Significance
	Mean	SD	Mean	SD		
Before treatment	4.31	0.18	4.54	0.42	0.14	NS
After hardening treatment	Group 1 (Hardener)		Group 2 (Beeswax)			
	1.45	0.32	1.49	0.17	0.71	NS
After heat treatment	Group1		Group 2			Significant At p<0.05 level
	2.19	0.53	1.64	0.31	0.01	

Unpaired t-test analysis showed no significant difference in surface roughness between the groups before and after hardening treatment; however, after heat treatment, a significant difference was observed, with Group II (beeswax) exhibiting lower roughness than Group I (p < 0.05).

DISCUSSION

Despite the increasing adoption of digital workflows in dentistry, the traditional lost-wax casting technique remains essential in certain clinical situations. It is particularly important for fabricating complex frameworks such as long-span bridges and removable partial dentures, where digital systems may have limitations in managing undercuts and large anatomical structures.The accuracy of conventional casting largely depends on the type of investment material used. Phosphate-bonded investments are widely preferred due to their compatibility with high-fusing alloys, along with their superior thermal stability and mechanical strength[2].

Cast partial denture fabrication involves duplicating the master cast to produce a refractory cast using phosphate-bonded investment material. Although these materials offer good thermal and mechanical properties, their inherent ceramic brittleness makes them susceptible to abrasion, making it difficult to preserve fine surface details during wax pattern fabrication[4].

This may be due to the larger particle size of the refractory material used in the investment[5]. Hence, careful handling of the refractory cast is necessary to maintain surface detail and achieve an accurate fit of the final partial denture framework.

Refractory casts in dental laboratories require complete drying after separation from impression to ensure strength, surface hardness, and dimensional accuracy[9]. As room-temperature drying is time-consuming, hardening agents or surface coatings such as waxes, sprays, and cast hardeners are used to improve durability and surface quality[4,5]. Common natural waxes include beeswax, carnauba, ceresin, and paraffin[6]

Beeswax is a animal wax produced in beehives, with a melting point range of 62°C to 64°C. It is primarily composed of fatty acid esters, hydrocarbons and long-chain alcohols. In medicine and dentistry, it is widely used in processes such as casting and coating pills, owing to its favorable handling properties and antimicrobial effects [10,11]

Cast hardeners are chemical agents applied to set investment molds, usually by dipping, to improve mechanical properties and prevent surface degradation before burnout. They enhance surface strength, reduce roughness, and minimize water-related erosion in phosphate-bonded investments [5].

Yassen ZN and Hummadi IM[6] compared the effects of different waxes on the surface roughness of phosphate-bonded investment material. The results indicated that there was significant decrease in surface roughness values after hardening treatment, supporting the current study's findings that hardening treatment decreasing the surface roughness values.

Jain A et al[3] evaluated the effect of Kalthärter cold hardener on the surface hardness and roughness of a commercially available phosphate-bonded investment material under varying loads and depths. Analysis showed that there was a significant difference in the surface roughness after hardening treatment. These results support the present study's conclusion that surface roughness decreases after applying hardeners.

Saji P et al (2017)[5] compared the effectiveness of cast hardening agents (Paraffin wax, beeswax and Okodur cold hardener) on surface abrasion resistance, hardness and detail reproduction for two commercially available refractory investment materials The findings indicated that these agents improved abrasion resistance and surface hardness, but they adversely affected surface detail reproduction.

The strength and surface properties of phosphate-bonded investments are influenced by factors such as binder composition, refractory particle size, binder-to-refractory ratio, and heat treatment conditions, which in turn affect their setting behavior, microstructure, and thermal performance[7].

Preheating is a critical step in investment casting with phosphate-bonded investments, as mold temperature directly influences the surface roughness of the final cast[12]. Introducing the mold into a preheated furnace after reaching peak exothermic setting ensures sufficient strength to withstand thermal shock, as most reactions and setting expansion are complete. This is likely due to silica, which aids thermal expansion and forms silico-phosphates on heating, thereby enhancing strength[2]

However, phosphate-bonded investments begin to deform at temperatures above 900 °C, showing thermal shock cracking along with softening and partial melting. This is mainly due to the temperature difference between the molten metal and the investment mold. Additionally, thermal interaction between the investment and molten cobalt–chromium alloy can affect the accuracy and detail reproduction of dental castings[8,13]. At temperatures exceeding 900°C, especially beyond 1375°C, chemical degradation of the investment material begins. This includes the breakdown of phosphate binders and transformation of crystalline silica, leading to mold disintegration, increased surface roughness and reduced casting accuracy. PBIs typically achieve optimal strength and surface smoothness at firing temperatures between 800°C and 900°C [8,14].

This in vitro study assessed how surface treatments and heat treatment affect the roughness of phosphate-bonded refractory casts used in cast partial denture fabrication. Twenty standardized specimens were divided into two groups (n=10): Group I was treated with a commercial model hardener and the Group II was treated with beeswax. Surface roughness (Ra) measurements were taken initially and after application of the respective hardening agents and finally after a controlled heat treatment at 875 °C for 60 minutes followed by gradual cooling. Statistical analysis (Student's t-test) demonstrated that both hardening treatments and heat treatment significantly reduced surface roughness compared to the untreated specimens (baseline) in both groups.

CONCLUSION

With in the limitations of above study following conclusions were drawn:

1.The surface roughness values of both group I and group II specimens produced decreased surface roughness values after application of hardening agents and after heat treatment.

2.There is no significant difference between two groups before and after hardening treatment and there was significant difference after heat treatment.

Further studies are necessary to optimize the surface quality of refractory casts and to evaluate the long-term effects of various hardening agents and heat treatments

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