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ORIGINAL RESEARCH

A Comparative Evaluation of Six Commonly used Types of Die Materials for the Property of Abrasion Resistance, at Two Time Intervals: An *in vitro* Study

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ABSTRACT

Background and objectives: This *in vitro* study evaluated and compared the abrasion resistance of types IV and V gypsums, resin-modified type IV and type V gypsums, synthetic gypsum, and epoxy resin die material at two different time intervals spanning a period of 24 hours.

Materials and methods: A total of 10 dies of each die material were fabricated and tested for abrasion resistance at each time interval. An average of five readings was taken for the test, measuring the rate of abrasion of the materials.

Results: All the tested properties of the epoxy resin material were far superior to those of the other materials (being tested). Resin-modified type IV gypsum had significantly better abrasion resistance than its type V counterpart at setting. However, when tested at 24 hours, both materials had comparable resistance to abrasion, which was the highest among the gypsum-based materials.

Interpretation and conclusion: Epoxy die resin had the most superior physical properties of all. A significant decrease in the rate of abrasion (−38 to −83%) was noted, when the gypsum-based products were tested at 24 hours. From the data obtained in this study, it is recommended that when gypsum-based materials are used, to wait at least 24 hours prior to separating casts from impressions (and subsequent laboratory procedures) to avoid damage to the casts and dies.

Keywords: Gypsum, Die material, Epoxy resin, Transverse strength, Time interval.

Abbreviations: RR IV: Resin modified type IV gypsum; RR V: Resin modified type V gypsum; S: Synthetic gypsum; V: Type V gypsum; IV: Type IV gypsum.

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INTRODUCTION

The use of indirect techniques for the fabrication of prosthodontic restorations has become almost universal today. The success of any indirect technique is dependent on, among other things, the availability of a die material that has ideal properties of strength, detail reproduction, dimensional accuracy, abrasion and fracture resistance, universal compatibility with impression materials, ease of manipulation, long shelf life and economics. Abrasion resistance is necessary for accurate adaptation and finishing procedures at the critical marginal areas of the wax patterns and the subsequent restorations. Some of the materials that have been used as die materials include types IV and V gypsum products, gypsum products modified with the incorporation of resins, hardener solutions, various surface coatings and a variety of other hardening treatments, silicophosphate cements, zinc phosphate cements, filled and unfilled polyurethane and epoxy resins, silver and copper amalgam, bismuth alloys, silver, copper and bronze in electroplated form, investment materials as well as acrylic and composite resins.[1-13]

Dimensionally, accurate die materials are critical to the fit of fixed prosthesis. Benefit of an accurate die material becomes even more important as the span and complexity of the prosthesis increases.[14] The need for manipulation of the master cast in extensive reconstruction requires a material that is not easily abraded, fractured or otherwise damaged. Convenience dictates that the materials have ease and efficiency of manipulation, compatibility with different impression materials, lack of toxicity and economic feasibility.

This study investigates six of the commonly used classes of die materials, with one material taken as representative of the respective class. The classes of die materials studied as a part of this research project included epoxy resins, synthetic gypsum, resin-modified types IV and V gypsum products and conventional types IV and V gypsum products.

The purpose of the study was to evaluate and compare abrasion resistance, of the commonly used classes of die materials; over two time intervals that is at setting and 24 hours after setting.

MATERIALS AND METHODS

This study tested the following classes of die materials for the properties of abrasion resistance:

1. Type IV gypsum (Master Die Peach, IGC Technologies).
2. Type V gypsum (Master Keen Green, IGC technologies).
3. Resin-modified type IV gypsum (Resin Rock, Whip-Mix Corp).
4. Resin-modified type V gypsum (Resin Rock XL5, Whip-Mix Corp).
5. Synthetic gypsum (SynaRock XR, Dental Future Systems).
6. Epoxy resin (Die Epoxy 8000, American Dental Supply).

The tests for abrasion resistance were carried out at two different points in time: at setting and 24 hours after setting. For each time interval, 10 specimens for each material were prepared and tested for the property of abrasion resistance.

Master Die Specifications

A 6 mm thick steel circular disk mounted upon a base was used. The disk had a diameter of 67 mm. At the center, a 6.5 mm diameter central bore that went through and through the disk was present. The base had eight escape ways milled into it. Additionally, a circular channel 2 mm in depth and 4.1 mm in width ran around the circumference of the disk. A metal cap 2 mm thick was also used as a spacer, to maintain an even thickness of the impression material in all the custom resin trays used. This was fabricated such that it fit exactly onto the circular disk and all its walls had an even 2 mm thickness of metal (Fig. 1).

Impression Making and Sample Preparation

A total of 2 mm thick custom trays were prepared from autopolymerizing acrylic resin (Dental Products of India, India). The trays were allowed to stabilize for 2 weeks prior to use. A thin layer of universal tray adhesive (Universal VPS adhesive, GC America Inc, Alslip, Illinois, USA) was painted onto each tray and impressions of the master die were then made in a low viscosity addition polyvinyl siloxane impression material (Exaflex, GC America Inc, Alslip, Illinois, USA) (Fig. 2). The materials were proportioned according to the manufacturer's specifications and prepared as explained below (Fig. 3).

Fig. 2: Acrylic impression with completed impression

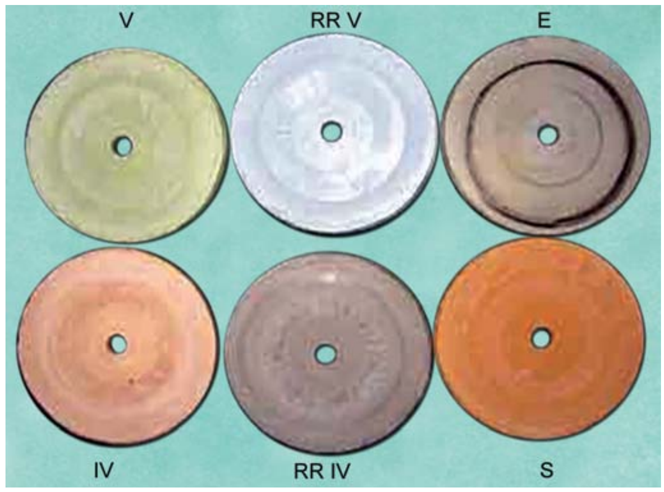

Fig. 3: Samples for the abrasion resistance test. Materials are identified by their color and code

Abrasion Testing

The apparatus used was a custom designed pin-on-disk[14] abrasion testing machine (MiniTribo, IIT Bombay, India). It had a functioning range of 120 to 500 rpm and was capable of applying abrasion loads from 3.68 N to 39.24 N (375-4000 gm).

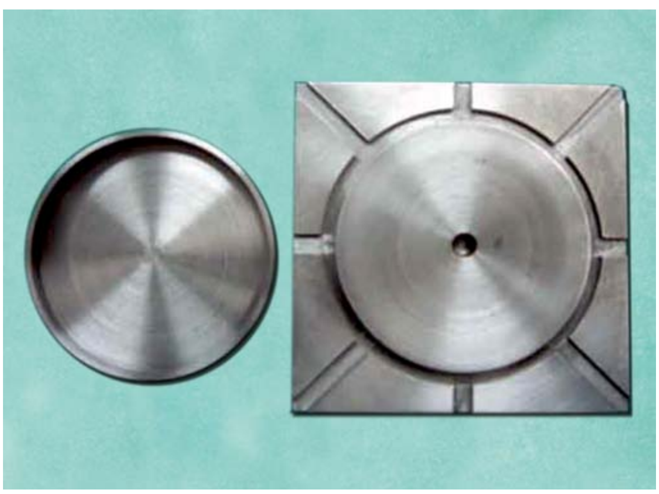

Fig. 1: The master die and the milled metal spacer of 2 mm thickness

The abrader was a 7.1 mm diameter, 15.5 mm long cylinder, made of hardened steel (Rockwell 'C' hardness of 62), which was sharpened to a flat blade at one end. The blade was positioned such that it was along the diameter of the circular face of the abrader. The abrasion load was maintained at a fixed constant of 3.77 N and the speed maintained at 120 rpm. The machine was adjusted to abrade the specimen for 20 revolutions or approximately 3.5 m.

The initial weight of the test specimen was recorded using the electronic weighing scale (A&D ER 180A, A&D Company Ltd, Japan). The specimen was then fixed onto the rotating table and abraded (Fig. 4). After abrasion, the weight was recorded as the final mass of the specimen and was subtracted from the initial mass recorded to obtain the mass lost due to abrasion, (change in mass Δm). The number of revolutions (N) as displayed on the machine was also

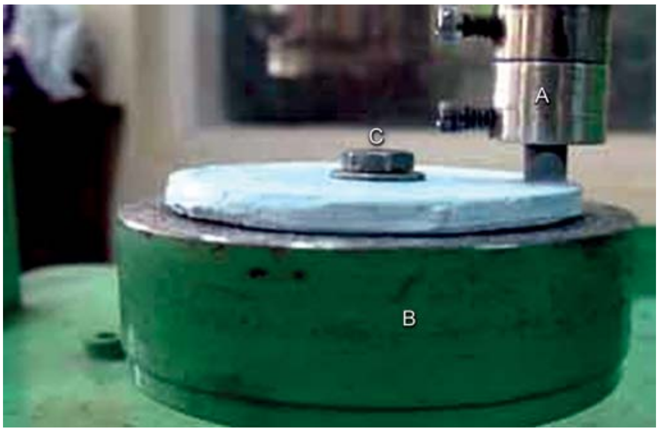

Fig. 4: The stainless steel holder with the custom abrader (A) held perpendicular and along the radius of the test specimen. Test specimen fixed to the rotating circular table (B) by a bolt through the central hole (C)

recorded. At the end of the abrasion tests for the specimen, the average of the inner and outer diameters (d) of the newly created wear track was calculated and recorded. This value was used to calculate the average perimeter (πd) of the wear track and, hence, the total sliding distance (S). Abrasion resistance was recorded as change in mass per millimeter or (Δm/S) for each of the six readings. The average value of abrasion resistance (Δm/S) was computed for that particular specimen. The next specimen was then tested and the same procedure followed until all 60 specimens had been abraded.

The next day, that is, 24 hours later, the same procedure was repeated on a fresh portion of the impression surface of the same test specimens as used previously. The observations for the different variables were recorded and calculations done as before.

RESULTS AND OBSERVATION

When looking at the results for this property, it is important to keep in mind that the numbers show the amount of mass the material lost as it got abraded. So if the material lost very little mass after the abrasion cycle, it is considered more abrasion-resistant than a material which has a higher value of Δm/S (change in mass per unit distance).

For example, Δm/S values for material IV (at setting) is 0.02330 mg/mm, whereas for material RR IV (at setting) it is 0.004030 mg/mm. This means that IV lost 0.02330 mg/mm and RR IV lost 0.004030 mg/mm after being abraded. Thus, we conclude that RR IV is more resistant to abrasion than IV (Tables 1 and 2).

The data, thus, indicate the amount or rate of abrasion that occurred. The higher the amount of abrasion, the lower the abrasion resistance of the material. Epoxy resin lost the least amount of material for both time intervals (0.000193 at setting and 0.000202 at 24 hours).

Type V gypsum lost the most material when abraded at setting (0.027410 mm/mg); however, at 24 hours, only 0.009405 mg/mm of material was abraded. This represents a 66% reduction in the rate of abrasion over 24 hours. Resin-modified type V gypsum followed by resin-modified type IV gypsum improved the most over 24 hours, with 83% and 76% reduction in the rate of abrasion respectively.

All the tested gypsum-based die materials show an increase in their abrasion resistance when tested at 24 hours. The resin-modified materials come close to the values of the epoxy material. The epoxy material shows the highest resistance to abrasion among all the tested die materials and remains as such when tested at 24 hours.

Table 1: The overall results and descriptive statistics of the experimental data of the abrasion resistance test for the six tested die materials, when tested at setting

Variables	*Mean rate of abrasion (mg/mm)*	*Standard error mean*	*Standard deviation*	*Variance*	*Coefficient of variance*	*Median*
IV	0.023304	0.00180	0.00571	0.00003	24.49	0.02450
V	0.027410	0.00332	0.01051	0.00011	38.34	0.03040
RR IV	0.004042	0.000188	0.000595	0.000000	14.75	0.003900
RR V	0.006790	0.001180	0.00373	0.00001	54.94	0.00475
S	0.018974	0.003390	0.01072	0.00011	58.29	0.01565
E	0.000193	0.000015	0.000047	0.000000	23.57	0.000200

Table 2: The overall results and descriptive statistics of the experimental data of the abrasion resistance test for the six tested die materials, when tested at 24 hours

Variables	*Mean rate of abrasion (mg/mm)*	*Standard error mean*	*Standard deviation*	*Variance*	*Coefficient of variance*	*Median*
IV	0.012864	0.000507	0.001604	0.000003	12.48	0.012450
V	0.009405	0.000420	0.001329	0.000002	14.15	0.009700
RR IV	0.000988	0.000166	0.000524	0.000000	52.91	0.001150
RR V	0.001182	0.000077	0.000244	0.000000	20.68	0.001200
S	0.011762	0.00161	0.00510	0.00003	43.39	0.01090
E	0.000202	0.000000	0.000000	0.000000	0.00	0.000200

The interpretation of the tables for the two sample t-tests is very similar to that of the Tukey data (Tables 3 and 4). However, these additionally give us the probability of one material being less than or greater that the other. Thus, abrasion resistance of material IV is less than that of material RR IV.

DISCUSSION

The surface hardness and abrasion resistance are two desirable properties of a die material. Hardness has often been used as an index of the ability of the material to resist abrasion and wear. However, numerous studies have shown that the two are not related and that hardness is a poor indicator of abrasion resistance.[15-18] Abrasion resistance of the die material is important during waxing and in the fabrication of metal margins.[19] Abrasion of the die at the finish line may result in a clinically unacceptable marginal adaptation.[20]

The initial null hypothesis of this study was that the mean values of the abrasion resistance test for all the tested materials would be the same.

However, the results of this study found significant differences among the tested materials at both time intervals, that is, at setting and at 24 hours.

Abrasion resistance of the epoxy resin material was found to be superior by far when compared with the other materials tested. Resin-modified type IV gypsum had significantly better abrasion resistance than its type V counterpart at setting. However, when tested at 24 hours, both materials had comparable resistance to abrasion, which was the highest among the gypsum-based materials. Type V gypsum had the least abrasion resistance of all the materials tested at setting. However, at 24 hours, its abrasion resistance was better than that of synthetic gypsum and significantly better than that of type IV gypsum which proved to be the least resistant to abrasion among the whole lot. A common

Table 3: The two sample t-tests for the amount of abrasion that occurred at setting

S. no.	*Pairs*	*T-test of difference = 0 or*	*T-value*	*p-value*	*Remarks**
1.	IV–V	IV < V	−1.09	0.148	NS
		IV > V	−1.09	0.852	NS
2.	IV–RR IV	IV < RR IV	10.62	1	NS
		IV > RR IV	10.62	0	HS
3.	IV–RR V	IV < RR V	7.66	1	NS
		IV > RR V	7.66	0	HS
4.	IV–S	IV < S	1.28	0.888	NS
		IV > S	1.28	0.112	NS
5.	IV–E	IV < E	12.8	1	NS
		IV > E	12.8	0	HS
6.	V–RR IV	V < RR IV	7.02	1	NS
		V > RR IV	7.02	0	HS
7.	V–RR V	V < RR V	5.85	1	NS
		V > RR V	5.85	0	HS
8.	V–S	V < S	1.9	0.963	NS
		V > S	1.9	0.037	S
9.	V–E	V < E	8.19	1	NS
		V > E	8.19	0	HS
10.	RR IV–RR V	RR IV < RR V	–2.31	0.023	S
		RR IV > RR V	–2.31	0.977	NS
11.	RR IV–S	RR IV < S	–4.23	0.001	HS
		RR IV > S	–4.23	0.999	NS
12.	RR IV–E	RR IV < E	20.31	1	NS
		RR IV > E	20.31	0	HS
13.	RR V–S	RR V < S	–3.23	0.004	HS
		RR V > S	–3.23	0.996	NS
14.	RR V–E	RR V < E	5.59	1	NS
		RR V > E	5.59	0	HS
15.	S–E	S < E	5.37	1	NS
		S > E	5.37	0	HS

*HS: Highly significant; NS: Not significant; S: Significant

Table 4: The two sample t-tests for the amount of abrasion that occurred at 24 hours

S. no.	*Pairs*	*T-test of difference = 0 or*	*t-value*	*p-value*	*Remarks**
1.	IV-V	IV < V	5.27	1	NS
		IV > V	5.27	0	HS
2.	IV-RR IV	IV < RR IV	22.24	1	NS
		IV > RR IV	22.24	0	HS
3.	IV-RR V	IV < RR V	22.76	1	NS
		IV > RR V	22.76	0	HS
4.	IV-S	IV < S	0.66	0.737	NS
		IV > S	0.66	0.263	NS
5.	IV-E	NA#			
6.	V-RR IV	V < RR IV	18.6	1	NS
		V > RR IV	18.6	0	HS
7.	V-RR V	V < RR V	19.22	1	NS
		V > RR V	19.22	0	HS
8.	V-S	V < S	−1.42	0.094	NS
		V > S	−1.42	0.906	NS
9.	V-E	NA#			
10.	RR IV-RR V	RR IV < RR V	−1.04	0.159	NS
		RR IV > RR V	−1.04	0.841	NS
11.	RR IV-S	RR IV < S	−6.64	0	HS
		RR IV > S	−6.64	1	NS
12.	RR IV-E	NA#			
13.	RR V-S	RR V < S	−6.55	0	HS
		RR V > S	−6.55	1	NS
14.	RR V-E	NA#			
15.	S-E	NA#			

*HS: Highly significant; NS: Not significant; S: Significant; #: All values in the column for epoxy are identical; Standard error, standard deviation; variance and coefficient of variance are all 0

finding for all the gypsum-based products was the significant increase in the abrasion resistance over the span of 24 hours.

The results of this test agreed with those of other investigators, who also found that the abrasion resistance of the epoxy material was higher than that of the gypsum-based materials.[2,3,17,18,21] The results are also corroborated by other studies that found a decrease in the amount of abrasion with an increase in the aging time,[3,15] possibly due to a loss of moisture content. The results of this investigation compared favorably with studies that showed that the resin-modified gypsum (RR IV) was the most abrasion-resistant material among the gypsum products tested[18,20] and that the conventional gypsum materials (type IV) had the highest abrasion rates when compared with filled and unfilled epoxies and metal dies.[21] The brittle behavior of the gypsum materials as compared to that of the epoxy die material has also been borne out by the results of the transverse strength tests in this study.

It has also been suggested that abrasion resistance can be improved by the impregnation of a supportive resin that acts to bind the gypsum matrix, filling subsurface voids and sealing the gypsum surface.[20,22] Impacted fracture and loss of surface material is, thereby, reduced through the reinforcement provided by the resin. This may explain why the resin modified materials; RR IV and RR V have the best abrasion resistance of all the tested gypsum-based materials.[22]

Abrasion resistance or wear is a complex process that may be influenced by the strength of the material, the surface qualities (roughness, texture) of the parent and opposing materials, third body wear (particle size), mode of fracture (ductile *vs* brittle material) and applied force.[23]

Loading weights have varied from 42 to 1000 gm and abrasion speeds employed have been as diverse as 0.6 to 30 mm/s and 78 rpm. In fact, even manually operated apparatus and simple manual qualitative tests[5] have been used for abrasion testing. The distances employed during the abrasion tests have been as wide-ranging as a single pass slide to 1.5 and 10 meter.[3,7,11,13,15-18,20,21,23,24] Although each device fulfills its purpose, there is no overall consensus about the best device to use to evaluate the abrasion of dental materials.

In this study, wear debris was minimized by loading in a unidirectional manner across the surface and using soft tissue paper to remove debris before each new reading.

It can be inferred that while all the gypsum-based materials benefit by waiting for 24 hours, materials RR IV, RR V, IV and V, are especially more abrasion resistant after a 24-hour period as compared with when used at setting. The epoxy resin material appeared to be as resistant to abrasion at 24 hours as it was at setting. Hence, this material can be used immediately at setting.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

The epoxy resin material developed most of its abrasion resistance property at setting itself and there was little change in its abrasion resistance at 24 hours. The abrasion resistance of all the gypsum-based materials increased significantly when tested at 24 hours as compared with that at setting.

The epoxy resin material had the highest abrasion resistance among all the tested materials. At setting, it was 121 and 142 times more abrasion-resistant than materials IV and V respectively. At 24 hours, the resin-modified materials were comparable to each other and were the most abrasion resistant materials among the group of gypsum-based materials. The epoxy material was, however, 5 times more abrasion-resistant than material RR IV when tested at 24 hours.

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