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BREAKING THE MOLD: AN EMPIRICAL ANALYSIS OF MOLDING AND CASTING EFFICIENCY

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ABSTRACT

The goal of this project was to assess the production quantity capability of casts from tin-based and platinum-based silicone rubber molds, while also considering the mold's rigidity under high and low stress environments. We compared six platinum-based molding rubbers (Mold Star® 16 FAST, Dragon Skin® 10 FAST, and EcoFlex™ 00-10, 00-20, 00-30, and 00-50) along with three tin-based molding rubbers (Mold Max® 10, Mold Max® 27T and Mold Max® 40). These products represent a variety of Shore hardness as well as pot life and cure times and are thought to have different archival capabilities. All molds were of a tooth of *Otodus* (= *Carcharocles*) *megalodon* and were poured using Smooth-Cast® 320 urethane resin. We made two one-part molds with each molding rubber, with the tooth positioned identically in each mold. Two tests were performed on each of the nine mold types—a short-term, high-stress and a long-term, low-stress test. For the short-term, or "torture-test," we poured the mold every eight minutes for 8-10 hours a day until the mold was exhausted to simulate a "rush production" prior to a major event. In contrast, for the long-term test we poured the mold once or, at most, twice a day to simulate occasional use over a longer time frame, although this is probably a better approximation of "occasional" use as opposed to true "archival" use, where the cast may only be poured a few times over several years. During curing, the resin reaches 60˚C, which slowly causes the inside of the mold to become dry, rigid, and more susceptible to tearing. This process is exacerbated during the short-term test due to the interior of the mold constantly experiencing high temperatures. Over the long-term test tin-based rubber hardens and cracks faster, and thus breaks down sooner, than platinum-based rubber. Under high production settings tin-based rubber consistently produces a higher volume of casts than platinum-based rubber. The flexibility of the materials also greatly matters as high Shore hardness materials tear too easily, yet highly flexible (low Shore hardness) materials cannot support their own weight. Our results show that tin-based shore 10A molds have the best combination of flexibility to durability for frequent to occasional use.

Keywords: experiment, casting, molding

RESUMO [in Portuguese]

O objectivo deste projecto era avaliar a capacidade de produção de quantidade de moldes a partir de moldes de borracha de silicone à base de estanho e platina, considerando também a rigidez dos moldes em ambientes de altas e baixas tensões. Comparámos seis borrachas de moldagem à base de platina (Mold Star® 16 FAST, Dragon Skin® 10 FAST, and EcoFlex™ 00-10, 00-20, 00-30, and 00-50) e três borrachas de moldagem á base de estanho (Mold Max® 10, Mold Max® 27T and Mold Max® 40). Estes produtos representam uma variedade de dureza de Shore assim como tempo de vida de mistura e tempo de cura e com capacidades arquivísticas estimadas diferentes. Todos os moldes foram de um dente de *Otodus* (= *Carcharocles*) *megalodon* e foram derramados utilizando resina de uretano Smooth-Cast® 320. Fizemos dois moldes de uma parte com cada borracha de moldagem, com o dente colocado de forma idêntica em cada molde. Dois testes foram efectuados em cada um dos nove tipos de molde – um de curta duração e elevada tensão, e um de longa duração e baixa tensão. Para o de curta duração, ou "teste de tortura", deitámos o molde a cada oito minutos durante 8-10 horas por dia até ao molde se esgotar para simular uma "produção acelerada" anterior a um grande evento. Em contraste, para o teste de longa duração deitámos o molde uma vez ou, no máximo, duas vezes por dia para simular o uso ocasional ao longo de um intervalo de tempo mais longo, embora tal seja provavelmente uma melhor aproximação de uso "ocasional" por oposição a uma verdadeira utilização "arquivística", na qual o molde pode apenas ser deitado algumas vezes ao longo de vários anos. Durante a cura, a resina atinge os 60º C, o que causa gradualmente o interior do molde ficar seco, rígido, e mais susceptível a rasgar. Este processo é exacerbado durante o teste de curta duração devido ao interior do molde ser constantemente exposto a altas temperaturas. Ao longo do teste de longa duração a borracha à base de estanho endurece e quebra mais facilmente, logo degrada-se em menos tempo, do que a borracha à base de platina. Sob condições de elevada produção a borracha à base de estanho consistentemente produz um maior volume de moldes do que à base de platina. A flexibilidade dos materiais é também de grande importância uma vez que materiais com dureza de Shore alta rasgam com demasiada facilidade, enquanto materiais muito flexíveis (dureza de Shore baixa) não suportam o seu próprio peso. Os nossos resultados mostram que os moldes com Shore 10ª à base de estanho possuem a melhor combinação de flexibilidade e durabilidade para utilização ocasional a frequente.

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INTRODUCTION

The replication of fossils is an integral part of paleontology. It allows for researchers to produce additional specimens to study and share, for educators to provide students a more tactile experience, and for the public to own something meaningful from a museum. The process of molding and casting has been the primary tool for paleontologists to replicate fossils since the beginning of the science. The molding and casting process consists of two main parts. Molding is accomplished by submerging an object with a molding material, in our case a two-part mix of liquid silicone rubber. Once the molding rubber sets the original object can then be removed. This leaves a hollow space, or void, in the mold in the shape of the original object. This void can then be filled with a casting agent, such as plaster, foam, or plastic. Once the casting agent has set inside the mold, it can be removed and serve as a copy of the original object.

While molding and casting is an inherently simple process, there are hundreds of different combinations of mold materials, fossils, and mold designs to complete the task on a near-infinite number of possible objects. Molding and casting in paleontology is, in large part, a technique passed from one practitioner to the equivalent of a student or apprentice, often in a near guild-like setting. Although there is some published literature on the subject of molding and casting in paleontology (Goodwin and Chaney, 1994) and numerous resources compiled by the fossil preparation community (Association for Materials and Methods in Paleontology), truly standardized tests of materials on fossils remain rare. The primary goal of this project is to collect empirical data to molding and casting in order to quantify the performance of two types of commonly used mold material in order to determine if one mold material is better than another.

For this experiment we chose to use a tooth of the giant extinct shark *Otodus* (=*Carcharocles*) *megalodon* (Fig. 1A), which is large enough to easily examine but not so big as to require large volumes of molding and casting materials. Other practical reasons for our choice of this specimen included: it has a simple triangular shape, yet a high level of detail (serrations), smooth areas (crown), and rough texture and cracks on the root. This single fossil therefore provides a range of different surfaces to capture, making it an ideal candidate for testing mold detail fidelity. *O. megalodon* is the

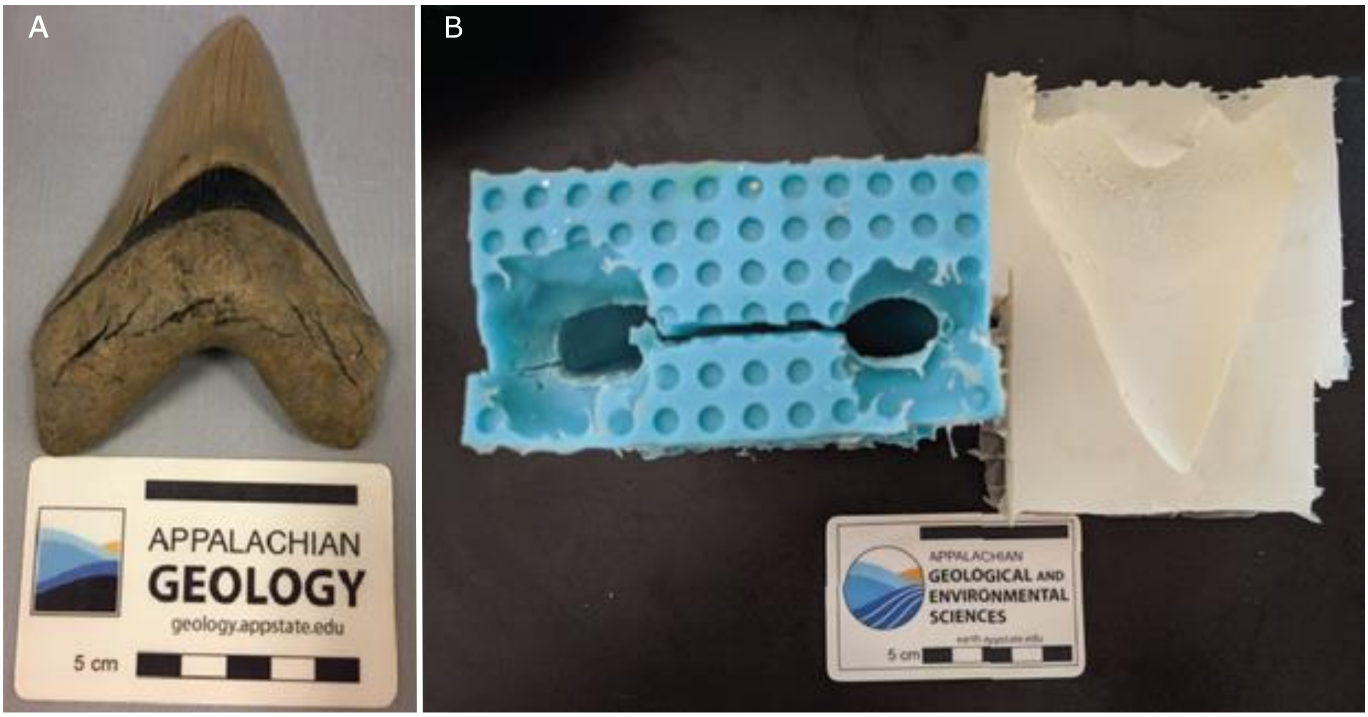

Figure 1: (A) *Otodus megalodon* tooth. (B): Example mold with bisected mold. Blue mold is Mold Star 16 FAST and clear mold is Dragon Skin 10 FAST. All photos shown with the same scale bar.

state fossil of North Carolina, widely recognizable, and sought-after, and thus the hundreds of casts generated over the course of our experiments were readily incorporated into our educational and outreach initiatives.

With institutions having a need for molding and casting it is important to consider budget constraints as well as time to select the correct material. Simple, recognizable fossils are important for outreach, teaching, and gift stores. Pocket, one-part, molds are the simplest and fastest way to replicate common three-dimensional fossils such as individual bones or teeth (Described further in Methods).

All materials we used were obtained from a single vendor (Reynolds Materials in Charlotte, NC) and are manufactured by Smooth-On, Inc. This is not an endorsement of either the vendor or manufacturer, but we felt it important to compare materials made by a single manufacturer to best control for any vagaries of the manufacturing process or proprietary formulations. This was especially important as we experimented with different Shore factors, so that we knew each material had been evaluated in a similar fashion.

METHODS

Mold preparation

Pocket molds, also known as one-part molds, were used exclusively for this experiment. Pocket molds can be made very quickly and work well with the triangular shape of a *O. megalodon* tooth. Multiple-part molds are more complex as they introduce more surface area, so they were omitted from this experiment. Due to the high detail of the crown and the top of the roots, we decided it was not worth the extra materials and time to completely mold the roots. In order to mold more efficiently the roots were used as pour holes (sprues) since the details captured on them would be minimal. Mold wall construction was accomplished with Legos®. These blocks are metric (1 cm tall) and, when properly fitted, watertight, rendering volume calculations for material required simple. The blocks also ensure that the mold walls are uniform in size, and therefore strength, and standardize the amount of molding material used for each mold throughout the experiment. In each mold the tooth was placed with the crown facing up so that the roots would serve as the pour holes once the mold set. Sulfur-free clay was used to secure the tooth in place. Each molding rubber was mixed and slowly poured into a corner of the Lego container to help eliminate air bubbles. The container was also tapped to help release any air bubbles trapped inside. Vacuum degassing was not used in this experiment. Once the mold cured (pot life and cure times given in Table 1), the tooth was removed from the mold by cutting the cured

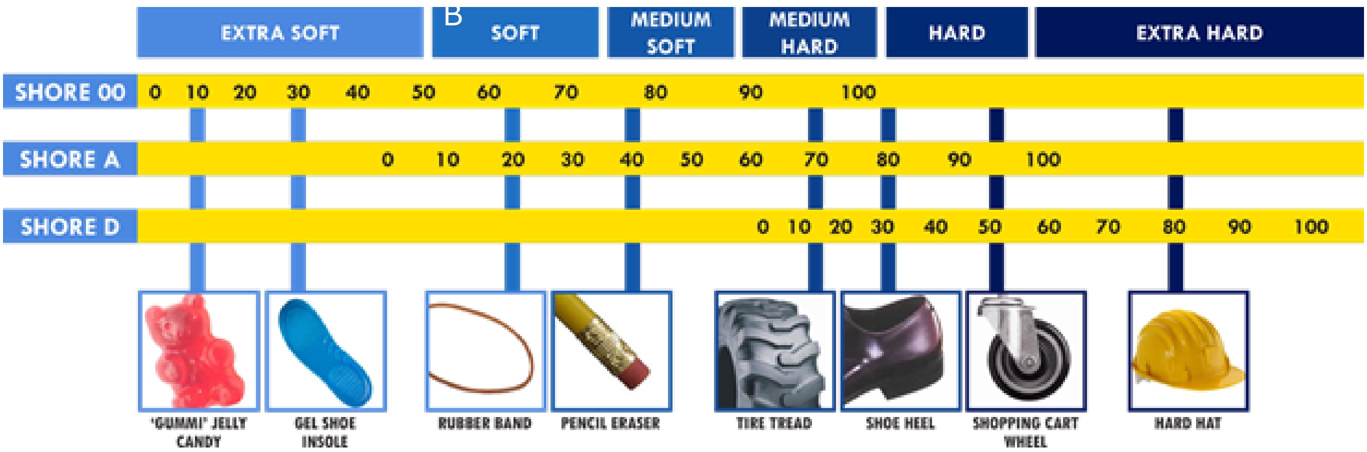

Figure 2: Shore Value Hardness compared to common materials. Modified from Smooth On.

Table 1: Tin-and-platinum-based silicone rubber cost, pot life, cure time, and shore hardness.

Material		Cost per kg Trial Unit	Price per Gallon Unit	Pot Life (min)	Cure time (hour)	Shore Hardness
Tin-Based	Mold Max 40	$27.25	$113.96	45	24	40A
	Mold Max 27T	$28.49	$95.04	45	24	27A
	Mold Max 10	$27.25	$103.30	45	24	10A
Platinum-Based	Mold Star 16 FAST	$32.22	$185.05	6	0.5	16A
	Dragon Skin 10 FAST	$32.21	$196.58	8	1.25	10A
	EcoFlex 00-50	$32.21	$196.58	30	4	00-50
	EcoFlex 00-30	$32.21	$196.58	30	4	00-30
	EcoFlex 00-20	$32.21	$196.58	30	4	00-20
	Ecoflex 00-10	$32.21	$196.58	30	4	00-10

rubber along the root to create a wide enough opening for removal. Rubber bands were used to hold the mold together during casting. All casts were poured using Smooth Cast 320 urethane resin, which has a pot life of 3 minutes and cure time of 10 minutes. During curing Smooth Cast 320 will reach 60 degrees Celsius. All molds and casts were generated by the senior author to remove variables related to individual technique and experience. An example of the mold design is seen in Fig. 1B.

Material

In order to create consistency in the molding materials we used only products from the molding and casting manufacturer Smooth-On.

All molding material information is also shown in Table 1. Three tin-based molding rubbers were used: Mold Max 40, Mold Max 27T, and Mold Max 10. All these materials have a 10:1 ratio of part A to part B by weight when mixing. Six platinum-based molds were used: Mold Star 16 FAST, Dragon Skin FX 10, EcoFlex 00-50, EcoFlex 00-30, EcoFlex 00-20, and EcoFlex 00-10. Materials were chosen to show variance in the shore durometer value. We use shore values of A and 00, each value is scaled from 0-100 to value relative hardness. All materials are scaled on shore A except for EcoFlex material which uses the 00 scale. Shore A is the most common hardness scale to use in molding and casting (Goodwin and Chaney, 1994: 238). As an example, Mold Max 10 has a shore hardness of 10A and EcoFlex 00-50 has a shore hardness of 00-50. Fig. 2 shows common objects compared to shore hardness values.

A gram scale with a tolerance of 0.01 grams was used for accurately dispensing the 10:1 ratio of molding materials. The 1:1 ratio materials were mixed by volume, with equal volumes of Part A and B poured into identical containers. The numbers after the product name denote the Shore Scale hardness. The casting agent used here is Smooth Cast 320 colored by Silc Pig and UVO dyes to help organize and visualize the quality of the casts. As a mold is used it begins to dry out and stick to the casts. To increase the life of all molding rubbers we used the mold release agent Mann Ease Release 200 both when molding and for each cast.

All molds and casts were created in a lab at standard room temperature (~20-22°C), with no atmospheric adjustments, over the course of eighteen months. Nitrile gloves and face masks were used to prevent contact with the material. These molds were not vacuum degassed (no air bubbles were found in the resulting casts caused by creation of the mold).

Long-Term Test

A true "long-term" or "archival" test of mold longevity over months to years of rare to no use was beyond the scope of this project, especially as additional factors, such as temperature and humidity of storage conditions, would probably have significant effects. Thus, the long-term test here emulates occasional to frequent museum use while reducing the effects of temperature. Each mold was poured occasionally—once, or at most twice, a day, using Smooth Cast 320. Approximately 30 minutes after the pour (or when the mold returned to room temperature) the cast is removed, and the mold not touched until the next day to eliminate any effects of resin continuing to react with the mold after hardening. Each cast was evaluated using a scoring system (see results, below), and the test was complete once visible pieces of the mold have been torn by the cast, or the mold no longer fits together properly.

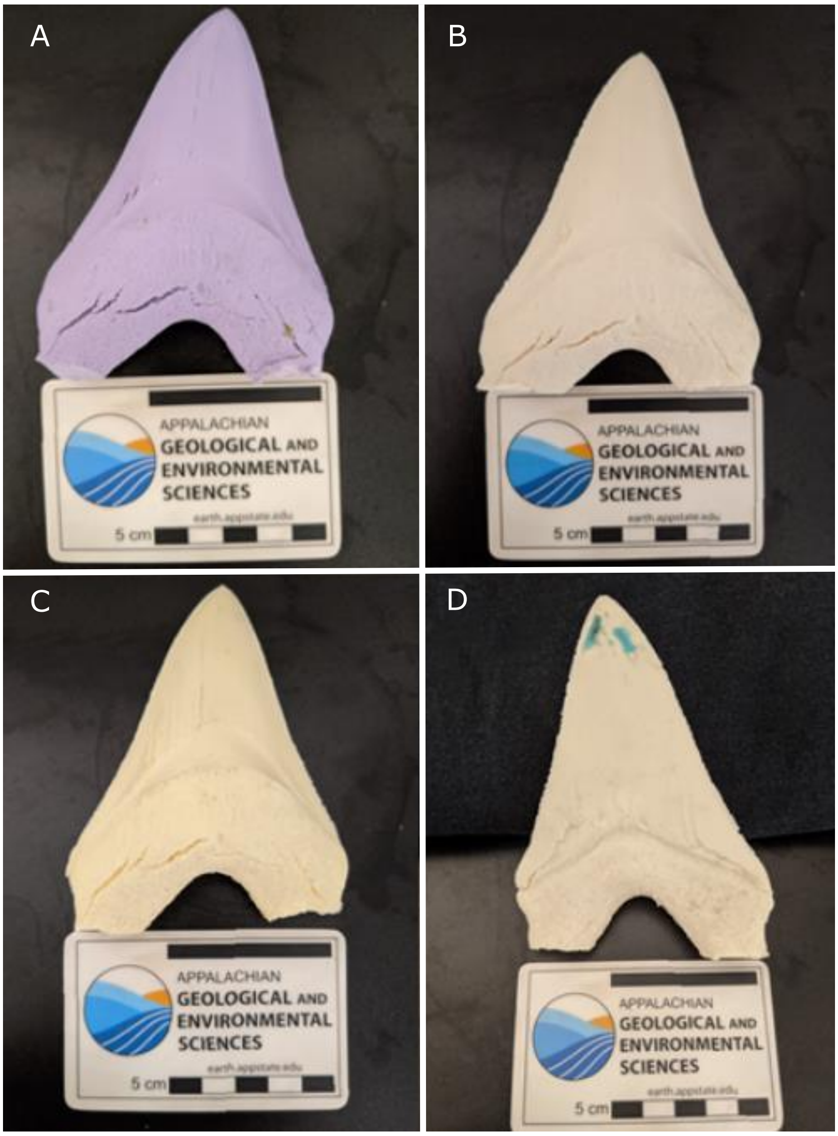

Figure 3: Examples of the different cast quality ratings. (A) Quality 4 cast. (B) Quality 3 cast. (C) Quality 2 cast. (D) Quality 1 cast. All photos shown with the same scale bar. Cast color is a result of added dyes and does not affect quality rating.

Short-term Test

The short term, or "torture" test, evaluates a mold's resilience to high stress and temperature. Each mold was poured as frequently as possible during the day. This test is intended to emulate frequent use of a mold in "production" mode, such as before a major event. Smooth Cast 320 can be mixed, poured, and pulled in as little as 10 minutes. This test lasted anywhere from less than one hour to ten hours. Again, each cast was evaluated using the scoring system outlined previously, and the test was complete once visible pieces of the mold were torn by the cast, or the mold no longer fits together properly.

RESULTS

Performance Evaluation

In order to generate empirical data from the resulting casts we created a simple quality scale. Casts were ranked as 4, 3, 2, and 1 depending on their quality, with 4 the highest and 1 the lowest. Examples of each of the qualities can be seen in Fig. 3. The differences in quality were evaluated without the aid of a microscope and are assessed by sight and touch. A quality 4 cast has few, if any, details differing from the original fossil. The crown should be smooth, all serrations captured, and the rougher texture of the root accurately replicated. We place the highest value on quality 4 casts as these are "research-grade," and, once painted, would be almost indistinguishable from the original fossil. Quality 3 casts have minor, but noticeable faults. Quality 3 casts are products of the beginning of mold rubber degeneration. Commonly the first issues are not all serrations captured or the crown has begun to lose its smoothness. At this point the casts are still of high quality, but due to the minor defects we consider these as outreach quality or museum gift store level. As the mold rubber begins to break down, its flexibility begins to decrease, leaving it with a more "dried out" feeling to the touch, which leads to cracks and roughness to the mold. Quality 2 casts have major structural problems that are immediately apparent on the resulting casts. For example, as the mold rubber continues to degenerate it no longer fits together properly, and this leaves seam lines on the cast. Along with the mold rubber no longer fitting flush, the crown will lose its smoothness. Quality 2 casts are only usable as education tools with significant sanding and other treatment. Quality 1 casts occur when the mold rubber has failed. Typically, this occurs when the mold rubber stiffens from extended use and, as the casts are removed large (1-15mm) pieces of the mold rubber rip out. Once this occurs the mold rubber is no longer usable. Every sequential cast will tear larger voids into the mold rubber.

Scoring System

We considered quality 4 and quality 3 casts to be the desirable product of molding and casting operations; while quality 2 molds are usable, we felt that the best evaluation of material was to see how many high-quality casts a mold would yield. Each mold was therefore scored as a function of the number of quality 4 and quality 3 casts. The score was the sum of the number of quality 4 casts multiplied by 4 and quality 3 casts multiplied by 3. Thus:

Score = (# of quality 4 casts x 4) + (# of quality 3 casts x 3)

Using this system, materials with higher scores yield more high-quality casts than those with lower scores, and, for materials that yield a similar number of casts, those that yield more quality 4 casts will score better than those that produce more quality 3 casts. The scores are presented in Table 2, and illustrated graphically in Figs. 4 and 5, but we provide additional summary information in the following section. Molding materials are sorted first composition (tin-based, then platinum-based), and then by flexibility according to shore scale.

Tin-Based Silicon Rubber

Mold Max 40

Mold Max 40 is a tin-based silicone rubber with a shore value of 40A. Its part A and part B have a mix ratio of 10:1 by weight. Mold Max 40 is the most rigid material that we tested over this experiment. It was predicted that the higher rigidity would make it less susceptible to tearing. While this may be true, this material is too rigid, and it was extremely difficult to remove casts from the mold rubber. Additional cuts into the mold were made in order to properly remove the casts. These extra cuts increased the surface area and appeared to have sped up the eventual failure of the mold material.

Long Term Test

Mold Max 40 produced 22 quality 4 casts and 1 quality 3 cast giving a score of 91. It is the fifth best performing mold material during the long-term test. Typically, we do not stop casting until a quality 1 cast is produced. Due to a resin mixing error the mold material became coated in partially mixed resin. We attempted to clean the mold and continue the test, but our efforts proved futile. While this test was cut short, given the tears beginning on the walls of the mold we determined it was not worth repeating the test.

Short Term Test

Mold Max 40 produced 18 quality 4 casts, 4 quality 3 casts, and 17 quality 2 casts giving a score of 84. It is the fifth best performing mold material during the short-term test. Similar to the long-term test, during the short-term test additional cuts had to be made to the mold material, shortening its life. Due to these cuts having to be made during the quality 3 casts, quality quickly dropped and was sustained at quality 2. Even with multiple rubber bands and bracings with cardboard and clamps, the mold was unable to properly fit together ending its performance.

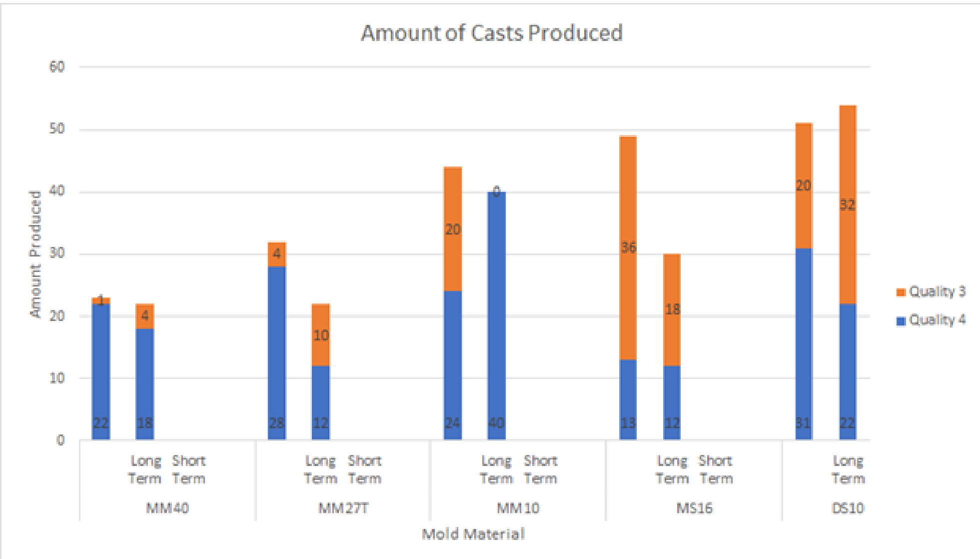

Figure 4: Amount of quality 4 and 3 casts produced by each test.

Mold Max 27T

Mold Max 27T is a tin-based silicone rubber with a shore value of 27A. Its part A and part B have a ratio of 10:1 by weight. The paleontology undergraduate research lab at Appalachian State University typically uses mold materials of shore 16A and 10A. We decided to use a slightly more rigid mold to see if this extra rigidity would aid in preserving the quality of our casts longer. While performing adequately during both the long-term test and short-term test, the added rigidity was a negative instead of a positive. Similar to Mold Max 40, Mold Max 27T also required extra incisions into the mold material in order to remove the casts in a timely manner or without the aid of a second person. Even with the use of the release agent, it was very difficult to remove, and pressurized air was used on multiple occasions to release the cast from the mold material.

Long Term Test

Mold Max 27T produced 28 quality 4 casts, 4 quality 3 casts, and 4 quality 2 casts giving a score of 124. It is the fourth best performing mold material during the long-term test. Mold Max 27T, while not the most rigid, gripped the cast more tightly than any other material. This caused tears to form earlier in this mold material than any of the other tested materials.

Short Term Test

Mold Max 27T produced 12 quality 4 casts, 10 quality 3 casts, and 8 quality 2 casts giving a score of 78. It is the fourth best performing mold material during the short-term test. Mold Max 27T suffered similar issues to Mold Max 40 during the short-term test. Due to the higher rigidity of this material in comparison to 16A and 10A materials, it required extra incisions and was difficult to work with. The issue of cast gripping persisted regardless of the quantity of Mann Ease Release 200 used on the interior of the mold material.

Mold Max 10

Mold Max 10 is a tin-based silicone rubber with a shore value of 10A. Its part A and part B have a ratio of 10:1 by weight. Mold Max 10 is the standard mold material used at Appalachian State University's Paleontological Undergraduate Research Lab, in part because of how it performed for this project. Its shore rigidity of 10A and chemical composition make it an inexpensive and useful addition to the lab. The years of use of this material helped to prompt the entire experiment since this is the most used material by our lab. Tin-based silicone rubbers are less expensive to manufacture and

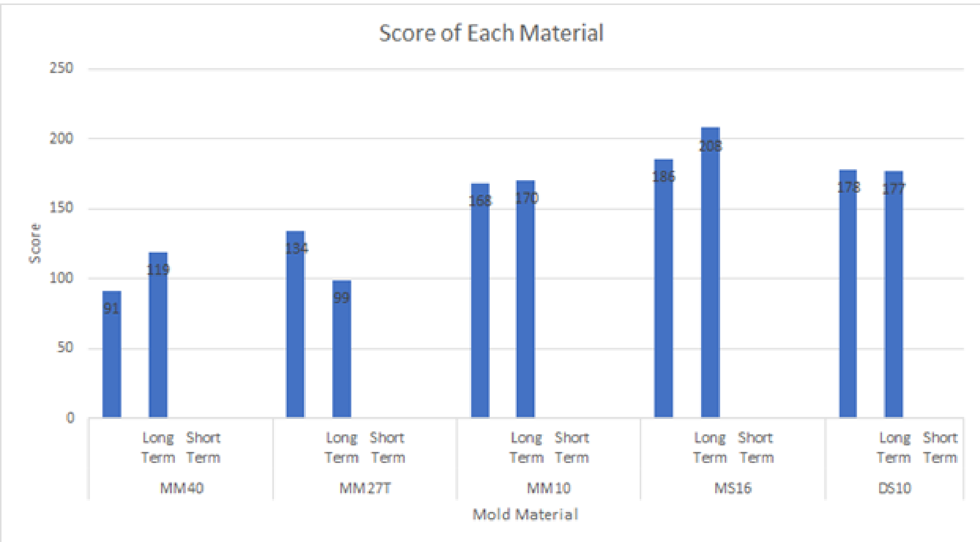

Figure 5: Score of each material from each test. Each figure has EcoFlex 00-50 through 00-10 removed due to low performance.

average half the cost of the platinum-based silicone rubbers.

Long Term Test

Mold Max 10 produced 24 quality 4 casts, 20 quality 3 casts, and 6 quality 2 casts giving a score of 156. It is the third best performing mold material during the long-term test. Mold Max 10 is a pink mold material once cured making dehydration of the mold easy to track. As the test ran the interior of the mold changed color to a lighter pink the dryer the interior became. Near the end of quality 3 production the interior was noticeably lighter than the exterior of the mold. It quickly stiffened, producing only 6 quality 2 casts before hardening completely, ripping the mold, and ending the test.

Short Term Test

Mold Max 10 produced 40 quality 4 casts giving a score of 160. It is the second-best performing mold material during the short-term test. Unlike any other material tested the quality of casts produced by Mold Max 10 dropped directly from quality 4 to quality 1. Similar to its performance during the long-term test, the interior of the mold began drying out through continued use. Unlike the long-term test however, this did not cause a drop to quality 3 casts. Cast 41 during this test tore a 1.0-centimeter hole into the interior of the mold material. This automatically makes the mold material produce quality 1 casts ending the test. Even though it did not produce any quality 3 or 2 casts, it produced more quality 4 casts in a single test than any of the other materials. The second highest performance was Dragon Skin 10 FAST during the long-term test with 31 quality 4 casts produced.

Platinum-Based Silicone Rubbers

Mold Star 16 FAST

Mold Star 16 FAST is a platinum-based silicone rubber with a shore value of 16A. Its part A and part B have a 1:1 ratio of material by volume. While not as prevalent in use at Appalachian State in comparison to Mold Max 10, Mold Star 16 FAST is the second most used material. In normal use we found there was not a significant difference between Mold Star 16 FAST and Mold Max 10, but Mold Max 10 costs half as much. This was the second material which helped to inspire this experiment, mainly due to its platinum base as opposed to Mold Max 10’s tin.

Long Term Test

Mold Star 16 FAST produced 13 quality 4 casts, 36 quality 3 casts and 9 quality 2 casts giving a score of 160. It is the second highest performing mold material during the long-term test. Similar to the pink color of Mold Max 10, the blue color of Mold Star 16 FAST pales and changes to an off white as it desiccates, providing a visual cue to help track its degradation. While Mold Max 10 tended to continually produce quality 4 casts then degrade quickly, Mold Star 16 FAST produced very few quality 4 casts, but noticeably more quality 3 casts. We are unsure as to why since the only other material that produces more quality 4 than 3 is Dragon Skin 10 FAST during the long-term test. As a shore 16A material it was easy to work with and did not require any extra incisions into the mold material to release casts.

Short Term Test

Mold Star 16 FAST produced 12 quality 4 casts, 18 quality 3 casts, and 37 quality 2 casts giving a score of 102. It is the third highest performing mold material during the short-term test. Mold Star 16 FAST behaved very differently during this test compared to the short-term test. During the long-term test, it produced primarily quality 3 casts, but during this test it produced a majority of quality 2 casts. While quality 2 casts can easily be used for outreach, we do not value quality 2 casts highly because of the extra work required to make them acceptable substitutes for quality 3 casts, which is why they are absent from the scoring formula. Given that other materials can produce a majority of casts as quality 4 or 3 we do not see a reason to value this material higher due to its poorer performance.

Table 2: Score of each mold material over the long term and short-term test. EcoFlex is not available in the short-term test due to lack of performance during the long-term test.

Material		Long Term						Short Term					
		Quality 4	Quality 3	Quality 2	Quality 1	Total	Score	Quality 4	Quality 3	Quality 2	Quality 1	Total	Score
Tin-Based	Mold Max 40	22	1	0	0	23	91	18	4	17	1	40	84
	Mold Max 27T	28	4	4	2	38	134	12	10	8	5	35	99
	Mold Max 10	24	20	6	0	50	168	40	0	0	10	50	170
Platinum-Based	Mold Star 16 FAST	13	36	9	0	58	178	12	18	37	1	68	177
	Dragon Skin 10 FAST	31	20	1	0	52	186	22	32	11	2	67	208
	EcoFlex 00-50	0	8	5	0	13	34	NA	NA	NA	NA	0	NA
	EcoFlex 00-30	0	7	4	0	11	29	NA	NA	NA	NA	0	NA
	EcoFlex 00-20	0	0	0	0	0	0	NA	NA	NA	NA	0	NA
	Ecoflex 00-10	0	0	0	0	0	0	NA	NA	NA	NA	0	NA

Dragon Skin 10 FAST

Dragon Skin 10 FAST is a platinum-based silicone rubber with a shore value of 10A. Its part A and part B have a 1:1 ratio of material by volume. Dragon Skin 10 FAST, along with the EcoFlex materials are mainly known for being skin-safe and special effects molding materials. Due to it being known to capture high details for movies, we felt it could be useful in capturing the details of our *O. megalodon* tooth. Dragon Skin 10 FAST also shares the same 10A hardness as Mold Max 10, which is a proven mold material in our lab. The rigidity of this material along with its incredible ease of use makes this one of the best materials used in this experiment.

Long Term Test

Dragon Skin 10 FAST produced 31 quality 4 casts, 20 quality 3 casts, and 1 quality 2 cast, resulting in a score of 184. This is the highest performing mold material during the long-term test. While Dragon Skin 10 FAST and Mold Max 10 share the same a shore factor of 10A, we found that Dragon Skin 10 FAST was noticeably easier to use. This was the easiest mold material to remove casts from out of the entire experiment. It produced 31 quality 4 casts, the highest amount of any material during the long-term test, with Mold Max 10 only producing 24 quality 4 casts.

Short Term Test

In the short-term test, Dragon Skin 10 FAST produced 22 quality 4 casts, 32 quality 3 casts, and 11 quality 3 casts giving a score of 102. This is the highest performing mold material during the short-term test. Again, Dragon Skin 10 FAST's high flexibility and good durability allow it to produce the most casts out of any material during the long-term test. Unlike its performance during the long-term test, however, it produced the second highest number of quality 4 casts, with Mold Max 10 producing 18 more quality 4 casts. It also produced more quality 3 casts than quality 4 casts, a trait only seen in Mold Star 16 FAST. Even during the high stress and constant heat of the short-term test, casts remained incredibly easy to remove from this material.

EcoFlex 00-50, EcoFlex 00-30, EcoFlex 00-20, EcoFlex 00-10

EcoFlex materials are all platinum-based silicone rubbers with a varying shore rigidity. Their part A and part B have a 1:1 ratio of material by volume. Similar to Dragon Skin 10 FAST these are also special effects mold materials. These were purchased after the tests were conducted with Dragon Skin 10 FAST. We wanted to test materials less rigid than 10A since decreasing the rigidity and increasing flexibility, up to this point, only improved the results of the mold material. The transition from a 10A material to a 00-50 material was too great. This is in part due to the shape of the mold. Because we used a 1-part pocket style mold without a mother mold, the material had to support its own weight. None of these materials had enough rigidity to hold their own weight.

Long Term Test

None of the EcoFlex materials were able to produce a single quality 4 cast during the long term. These materials were too flexible and even with outside support were unable to hold up their own weight, resulting in warped or otherwise deformed casts.

Table 3: Comparisons of the price per cast for each molding material.

					Short Term			Long Term		
Material Type	Material Mold	Mold Cost per Trial Unit	Mold Cost per Gallon	Resin Cost/Tooth	Total Casts	Cost Per Tooth Trial Unit	Cost Per Tooth Gallon Unit	Total Casts	Cost Per Tooth Trial Unit	Cost Per Tooth Gallon Unit
Tin-Based	Mold Max 40	$27.25	$113.96	0.8863	23	$2.07	$1.51	40	$1.57	$1.24
	Mold Max 27T	$28.49	$95.04	0.8863	38	$1.64	$1.20	35	$1.70	$1.23
	Mold Max 10	$27.25	$103.30	0.8863	50	$1.43	$1.14	50	$1.43	$1.14
Platinum-Based	Mold Star 16 FAST	$32.22	$185.05	0.8863	58	$1.44	$1.29	68	$1.36	$1.23
	Dragon Skin 10 FAST	$32.21	$196.58	0.8863	52	$1.51	$1.36	67	$1.37	$1.25
	EcoFlex 00-50	$32.21	$196.58	0.8863	13	$3.36	$2.78	NA	NA	NA
	EcoFlex 00-30	$32.21	$196.58	0.8863	11	$3.81	$3.12	NA	NA	NA
	EcoFlex 00-20	$32.21	$196.58	0.8863	NA	NA	NA	NA	NA	NA
	Ecoflex 00-10	$32.21	$196.58	0.8863	NA	NA	NA	NA	NA	NA

Short Term Test

Due to the poor performance of EcoFlex during the long term we determined it was not worth the material to conduct the short term test.

DISCUSSION

Mold Material

The platinum-based Dragon Skin 10 FAST and Mold Star 16 FAST, and the tin-based Mold Max 10 are the standout materials during both the long term and short-term test (Figs. 4,5). These three materials are similar in flexibility and their performance was very similar during testing.

There are slight differences such as Mold Star 16 FAST being slightly more rigid and Dragon Skin 10 FAST sharing the same rigidity as Mold Max 10, but appearing to be even more flexible. The major difference in these materials are that Dragon Skin 10 FAST and Mold Star 16 FAST are platinum-based silicone rubbers, and Mold Max 10 is a tin-based silicone rubber. Our long-term test's goal was to test a mold's use over a period of months. This time appears to be too short to properly test the durability of platinum and tin-based silicone rubbers. The difference in material did not appear to be an advantage or hindrance to either material.

Mold Flexibility

While the differences between tin and platinum-based silicone rubbers appear to be minimal to none during our testing, the flexibility of the mold material made a distinct difference in the usability of each mold material. Mold Max 40, the most rigid material tested, was nearly impossible to use as a one-part mold. Similarly Mold Max 27T provided problems with rigidity. While details of the resulting casts were acceptable, it sometimes required two people or an air compressor to remove the tooth. It is possible that materials of this rigidity would do better as a two-part mold since the two halves can be easily separated after each casting. On the more flexible end, with all EcoFlex materials, they were unable to support their own weight. Even with external support added none of these materials were able to produce a single quality 4 cast.

This leaves Dragon Skin 10 FAST, Mold Star 16 FAST, and Mold Max 10 as the remaining materials. Their shore 10A and 16A flexibility provides a great ratio of flexibility to durability. These mold materials were also extremely easy to work with in the lab. Casts are removed without much effort, but the molds were still rigid enough to hold their shape throughout testing. When assessing only flexibility as a reason to purchase, materials of shore 10A rigidity appear to be the best use for pocket style one-part molds.

Cost to Performance

The cost of production was calculated using the price of a trial unit (~1 kg) as well as gallon (weight varies by material) units. In the calculation resin is accounted for by the MSRP of Smooth Cast 320 ($88.63 USD) divided by 100 casts, which is the average number of teeth made from one two-gallon set (Table 3), which is thus $0.89 (89 cents/cast). In order to cast the tooth of *O. megalodon* one entire trial unit is used. The gallon units on average are eight times the size of the trial units so their price is divided by eight to account for the material being less expensive in bulk.

The Cost per Tooth (Trial Unit) formula is:

(Mold Cost per Trial Unit + (Total Casts * Resin Cost/Tooth)/ Total Casts

The Cost per Tooth (Gallon Unit) formula is:

((Mold Cost per Gallon/8) + (Total Casts * Resin Cost/Tooth))/ Total Casts

The three best performing materials overall across both tests are Dragon Skin 10 FAST, Mold Star 16 FAST, and Mold Max 10. The lowest cost of production is Mold Max 10 during both the long term and short-term test, costing $1.14 per cast using the gallon unit. While Dragon Skin 10 FAST and Mold Star 16 FAST performed similarly, their cost of production is higher. Dragon Skin 10 FAST cost at its lowest $1.25 during the long-term test using a gallon unit and Mold Star 16 Fasts coast at its lowest $1.23 during the same test. This is due to platinum-based silicone rubbers averaging double the price of tin-based silicone rubbers. Given its performance during both tests, and its difficulty in use we would not recommend Mold Max 27T. However, even as a platinum-based silicone rubber it has the lowest gallon unit MSRP at $95.04. Even as a low performing mold material, its low price makes it the least expensive mold used during the testing process.

If the goal is to create as many casts as possible it would be more economical to use the less expensive tin-based Mold Max 10 since it produces almost the same quality and quantity as the platinum-based Dragon Skin 10 FAST and Mold Star 16 FAST at approximately 2/3 the cost per cast.

CONCLUSION

When assessing the question of best mold material, it is important to remember the constraints of this experiment, mainly that of time and the shape of the mold. This was conducted over a period of months and used only one mold style—pocket style one-part molds. Our conclusions will be limited due to these variables. Giving a definitive best choice is near impossible due to the vast number of variables a preparator must sort through.

For short term projects that use a relatively simple fossil we recommend a tin-based shore 10A mold material. The years of use of Mold Max 10 by the Appalachian State Paleontological Undergraduate Research Lab as well as the Virginia Museum of Natural History shows Mold Max 10 provides an excellent ratio of durability:flexibility. Like any mold, these molds will desiccate and crack over long periods of use. Outside of the experiment Appalachian State has molds made with Mold Max 10 over five years old that are still usable for outreach programs. While Dragon Skin 10 FAST, Mold Star 16 FAST, and Mold Max 10 all produce many quality 4 and 3 casts during the short-term test, it is important to remember Mold Max 10 averages half the cost of the other two materials (Table 3). This lower cost further increases its capabilities for large scale projects which require a low output volume.

The cast quality difference between tin-based and platinum-based are negligible at the scale in which we operated. Given the results of the long-term test, platinum-based rubber molds can last for a longer amount of time on a shelf with occasional use compared to tin-based. We recommend the use of platinum-based mold materials for low production situations over a period of months and tin-based for higher production over a period of weeks, not unlike the original vendor’s recommendations when we began this project.

While the material of the mold was important in determining shelf life the more important trait of the material is its flexibility. We used a wide range of flexibilities in the molds from the rigid shore factor

40D to the extraordinarily flexible 00-10. At the over flexible end, the mold cannot even hold up its own weight causing distortion (EcoFlex). At the stiffer end, Mold Max 40 and Mold Max 27T, the mold has no elasticity and will tear instead of releasing. From our results, relatively flexible molding material, one with a shore value of 10A to 16A, provides the best ratio of flexibility:rigidity for simple pocket molds.

Future Studies

We feel it is important to begin adding empirical data to the science of fossil preparation. Experiments such as this can begin to create more resources for museum preparators, universities, and outreach programs. In the future the addition of different mold styles, different manufacturers, and a larger array of flexibilities will provide an additional understanding as to the best materials for each project.

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See also:https://vertpaleo.org/preparators-pdfs/#molding-and-casting

Original raw images at full resolution and animated material can be downloaded at
http://www.jpaleontologicaltechniques.com