Clarinet Mouthpiece Materials

Brent Smith, January 31, 2009

Abstract, purpose and scope

This is a review of information about clarinet mouthpiece materials and their effects on sound, playability and other items of importance to clarinet players. Sources of information are identified in the text (numbers in parentheses are posting numbers from the website http://launch.groups.yahoo.com/group/MouthpieceWork/). The purpose of this is to give information that an individual can use to form their own opinion about mouthpieces and materials, and whether materials really matter (to that individual).

Contents

I. Material from which the clarinet mouthpiece is made

Many different materials of wide-ranging properties have been used to make clarinet mouthpieces. There is considerable difference of opinion as to how much the specific material really matters in terms of the sound, playability, etc of the mouthpiece. In fact, this is a very controversial subject and often stirs considerable discussion and debate. There are many credible individuals that are fully convinced that the differences between various commercially-used mouthpiece materials are of no consequence. There are even more equally credible individuals who are convinced that the material is critical to mouthpiece sound and playability. Considerable experimentation and study has produced "evidence" that can be (and often is) used to argue either side of that question.

The purpose of this review is not to settle this argument, or to prove which side is right or wrong. The purpose here is simply to present information and reasoning on each side of the question. Understanding the facts allows you to make an informed determination for yourself about whether or not this actually matters to you.

Previously, a similar document was published By Roger McWilliams for saxophone. See the website http://hal9000.ps.uci.edu/does%20saxophone%20mouthpiece%20material%20matter.doc.pdf

II. Properties of materials

Now, and in the past, clarinet mouthpieces have been made from a variety of materials including natural materials (e.g. wood, bone, ivory, glass, "crystal") and synthetic materials (e.g. plastic, "hard rubber"). Synthetic plastics, resins and rubber-elastic materials came into existence with the development of polymer chemistry in the 1920's and 1930's and have pretty much displaced natural materials except glass. Several descriptions of mouthpiece materials have been published. (http://www.clarinetmouthpiece.com/nomenclature.asp) Notably absent from the list of materials commonly used to make clarinet mouthpieces are metal and ceramic. Why these have not been utilized more may seem puzzling at first. The most likely reasons are higher cost, more difficult manufacturing, and tradition. Players and manufacturers seem to be reluctant to adopt new materials with which they are not familiar.

Due to cost, availability, good performance, ease of manufacture and other reasons, hard rubber and plastic have become the most common materials for clarinet mouthpieces today. (5025)

For purposes of this discussion, properties of materials are divided into several categories like acoustic, aesthetic, manufacturing, and practical properties.

Practical properties include cost, durability, maintenance requirements, repair procedures, and the like. For example, a mouthpiece made of heavy lead crystal might be preferred by a professional player, but for a high school marching band player, it might not be as good a choice because its cost, ease of damage, and safety (younger players are more sensitive to lead exposure). Another practical example is that wood mouthpieces require more maintenance attention from the user than plastic or hard rubber mouthpieces. Durability is another very important practical property. For most players and manufacturers, cost is probably the single most important overall consideration in the selection of mouthpiece material.

Manufacturing properties include ability to be formed, machined, molded, faced, repaired, etc. Also, certain material may require more manual handling and/or more manufacturing steps. For example wood must be seasoned, cured, dried, pretreated with oil, extensively hand finished, etc. This leads to higher cost. Metal may be more difficult to machine than plastic or rubber, thus requiring more expensive forming techniques and equipment.

Aesthetic properties include appearance, color, feel, smell, taste, perceived (subjective) value, and the like. These properties might not be important to all players, but they are important to many. These are subjective and not necessarily related to the physical properties of the material. For example, if a player prefers a gold ligature because the player "knows" (right or wrong) it's the best material for a ligature, then that's an important property of the material for that player, and to the vendor.

Finally, there are the acoustic playing properties of the mouthpiece – its sound and playability. These are controlled primarily by the size and configuration of the chambers, the facing, rails, table, etc. According to many (perhaps most) players, another factor is the material from which the mouthpiece is made. Mouthpieces are made from various materials with different physical properties which, in theory, could cause them to behave differently acoustically. The three the most important physical properties of mouthpiece material related to its acoustic properties (in alphabetical order) are density, stability, and stiffness. Whether or not these are of practical importance is part of the purpose of this review.

For our purposes, stability can be defined as a material's ability to resist dimensional changes during use (short- or long-term), especially due to the effects of moisture and temperature variation. The stability factor is important because materials with better stability don't change size or shape when used or when aged. This is of primary concern because, as noted above, the size and shape of chambers, rails, etc have a very pronounced effect on the playing properties of a mouthpiece. Materials vary greatly with respect to short- and long-term stability.

Stiffness and density together are the main properties of materials that control the propagation of sound within a material. Stiffness is the ability of a material to resist temporary deformation when it is subjected to a force and is indicated by "Young's modulus". Materials with higher values of Young's modulus are stiffer. Sound travels faster through stiffer materials, all other factors being equal. The type of deformation that transmits acoustic waves is a temporary deformation or small "vibration" of the material. Density is the weight of the material per unit volume, usually expressed in grams per cubic centimeter. Sound travels slower through denser materials, all other factors being equal.

To understand the effects of mouthpiece materials does not require an in-depth knowledge of physics, but understanding the conceptual relationships between these properties can help explain why some material might behave differently from others. The actual numerical values of these properties are not so important to a conceptual understanding as the relative rank of various materials.

Sound travels compression waves in materials. The distance the wave travels in a given time is the speed of sound. In air at 70°F its speed is 344 meters per second or 13,650 inches per second. When all tone holes are closed, sound waves that are generated as a clarinet reed vibrates travel about 24 inches in 1/569 of a second to get to the bottom of the instrument, then some of the wave energy is reflected back up to the reed to drive it in a resonance oscillation. This forms an acoustic standing wave in the air column inside of the clarinet. For a "cylindrical" instrument like the clarinet (actually the clarinet is not totally cylindrical), this is ¼ of the total sound wave cycle, so it takes about 1/142 of a second to produce a full cycle in the clarinet waveform. Thus the note produced has a fundamental resonant frequency of about 142 vibrations per second or hertz (hz) when the clarinet is "cold" (70°F). As it warms up, the speed of sound in air increases which makes round trip take less time. Thus more round trips can be made per second, giving a higher frequency and a corresponding rise in pitch to about 147 hz when the instrument is fully warm. This is frequency of "low E".

The speed of sound in solids (and liquids) is much faster than in air. In steel, for example, the speed of sound is approximately 15 times as fast as in air. Therefore any resonant frequencies in the mouthpiece material itself or in the instrument body material would be very high due to the small size of the mouthpiece and the high speed of sound. In that case the "round trip" would be very fast -- well above the range of human hearing. But there is no question that the mouthpiece material in a clarinet vibrates at lower frequencies.

It's often stated that material in the mouthpiece does not vibrate to any significant extent, especially for thick-walled mouthpieces or very stiff materials. This is clearly not the case. When the reed slams shut against the tip rail, it sends a transmitted shock wave into the mouthpiece. Many (perhaps most) clarinet players use a "mouthpiece patch" to prevent transmission of these vibrations to the player's teeth and ears. The patch allows the player to hear what the listener hears -- sound transmitted through air (not through the mouthpiece). (604, 609, 630, 3859) If the mouthpiece material did not vibrate, then a mouthpiece patch would not matter. Furthermore, one can simply place a finger on the mouthpiece (or barrel or upper joint of the instrument) while it's being played and feel the vibrations. If the player stops the air flow, the sound stops and the vibration is no longer felt in the mouthpiece and the body of the instrument. The walls of the clarinet and the mouthpiece clearly do vibrate, and this can be easily observed. Saying that the body of the instrument does not vibrate is an example of the kind of folklore that often gets perpetuated as (incorrect) "common knowledge".

How the sound waves behave within the solid mouthpiece material (not in the air column of the instrument) is controlled by the material's stiffness and density, as well as the geometry and wall thickness of the mouthpiece. The stiffness refers both to changes in size (volume) of the mouthpiece material as well as changes in shape (shear deformation). Changes in volume as well as shape of the material itself can generate sound waves with many different characteristics. Stiffness, being a deformation due to the application of a force to the material, is somewhat related to hardness, but it is not exactly the same thing. Of course, the reaction of the mouthpiece material to vibrations is not only controlled by the material's properties but also the size and shape of the mouthpiece. More rigid materials allow for thinner but still rigid walls. This has an effect on the players comfort and oral cavity size.

Here are properties of some materials (http://www.engineeringtoolbox.com/ http://ecow.engr.wisc.edu/cgi-bin/get/bme/315/tyler/resources/material.properties.pdf and other sources)

Material	**Stiffness Young's Modulus Millions of PSI**	**Density in grams per cubic centimeter**
Rubber (soft)	0.0015 to 0.015	0.95 to 1.5
ABS plastic	0.33	1.0
Polycarbonate	0.38	1.30
Rubber (hard)	0.39	
Acrylic	0.46	1.4
Bone	1.3	Varies (1.0 to 2.0)
Oak Wood	1.6 (with grain)	0.69
Douglas fir wood	1.9 (with grain)	0.53
Glass	7.3 to 13	2.0 to 8.0
Aluminum	10	2.7
Gold	11	19.3
Silver	11	10.5
Brass	15 to 18	7.3 to 8.4
Steel	29	7.8
Diamond	160	3.5

The materials at the top of the list are more easily deformed and thus are set in motion more easily. This list is not complete, but simply indicates the incredible range of physical properties that are available in materials. The highest modulus on the list is over 100,000 times greater than the lowest.

There are extensive theories as to how sound travels in these materials, but their complexity is beyond the scope of this review, and probably of no interest to most readers anyway.

The previous comments are not intended to imply that the only effects that are important are the sound transmission or vibration characteristics of the material. For example, a material's ability to resist wear and warpage during use over time and other such properties (such as cost) are also very important.

III. Materials used in clarinet mouthpieces

Many materials have been used to fabricate clarinet mouthpieces, including wood, bone, ivory, hard rubber, plastic, glass, crystal, ceramic and metal.

a. Wood

Prior to the development of modern polymeric materials in the early 1900's, most mouthpieces were made of wood. In fact, there are still commercial mouthpieces available made from various woods. Woods of choice today are ebony, granadilla, cocobolo, and other very dense and hard woods. (http://www.lomaxclassic.com/mouthpieces.htm http://www.lebayle.com/) The drawbacks of wooden mouthpieces are their high cost and (reportedly) lower stability than other materials like hard rubber. The high cost of wood mouthpieces results from the extensive amount of hand working required to manufacture a mouthpiece from wood, compared to other materials.

Advocates say that wood is a desirable material for its ease of response and its warmth and color of sound. (5025) It is not unusual to find older wooden mouthpieces that play well after refacing. The sound is described as "not loud, but with a rich, interesting sound". This may be due to the fact that "most of them are small chamber mouthpieces which overwhelm the effect of the wood on the sound of the mouthpiece with the power of the smaller chamber." (5030)

On the other hand, wood is reportedly prone to cracking; it warps and shrinks over time; and it expands due to moisture absorption during use, thereby changing the pitch and response of the mouthpiece. (869, http://www.clarinetmouthpiece.com/nomenclature.asp) In addition, over time wooden mouthpieces require flattening the table periodically, even if the mouthpiece is well maintained. (5025, 5030) Distortion occurs due to force of the ligature as well as the effect of saliva. Statements about distortion, cracking and long-term instability make sense. But the often-stated idea that thermal expansion of wood actually causes significant intonation problems, seems to be just another example of incorrect "common knowledge". It's more likely that wet/dry dimensional changes (not temperature changes) are the cause of response and intonation problems in mouthpieces made of wood, for the following reasons.

As shown in the following table, wood expands more when heated than most other mouthpiece materials, with the notable exception of plastics like Delrin POM and acrylic. (USDA Encyclopedia of Wood, http://www.handyharmancanada.com/TheBrazingBook/comparis.htm, http://hyperphysics.phy-astr.gsu.edu/hbase/tables/thexp.html, Marshall et al., J. Dentistry, 25,441, 1997, http://www.indplastic.com/ http://www.unofficialbmw.com/images/delrinwhite.pdf)

Material Substance	Thermal expansion coefficient parts per million per degree C
Wood (across the grain)	250
ABS plastic	80
Delrin plastic rod	80
Acrylic plastic	60
Wood (with the grain)	35
Aluminum	23
Brass	20
Silver	18
Nickel-Silver	17
Copper	16
Stainless steel	15
Mild steel	13
Gold	14
Iron	13
Bone, ivory (variable)	10
Ceramic	10
Glass	9
Platinum	9
Tungsten	4
Zirconia	6
Quartz	0.6

It has been widely reported that most wood is dimensionally unstable. (5021) Significant facing changes can be measured between a cold dry mouthpiece and the same one when warm and moist. This varies with the type of wood. The wooden saxophone mouthpieces from Brancher are reported to be more stable than some others. (http://www.brancher-france.com/)

In addition to thermal expansion, wood is far more affected by exposure to moisture than other mouthpiece materials. Expansion due to wetting predominates over the expansion due to temperature changes. (USDA Encyclopedia of Wood) But, for whatever reason -- either heat or moisture -- wood does indeed expand more than most other mouthpiece materials listed above during the instrument "warm-up". These dimensional changes of a mouthpiece can cause changes of response and pitch. In the case of dimensional changes due to wetting, there are undoubtedly some irreversible changes (e.g. warping) that occur when the wood goes through many wet/dry cycles over a long period of time.

But the main cause of pitch change in clarinets has little to do with expansion of parts of the instrument itself by thermal or other causes like wetting. A clarinet changes pitch as it warms up because the speed of sound is faster in warm air. For example, suppose you pick up your clarinet "cold" at 70°F (21°C) and play it until it reaches your body temperature of 98.6°F (37°C). The temperature change is 16°C. If the clarinet is made of wood, the change in dimensions in length (with the grain) will be 35 X 16 = 560 parts per million (ppm) due to thermal expansion. This will cause a lowering of the pitch by 560 ppm due to the extra distance the sound wave has to travel to the bottom of the instrument and back to the reed. On the other hand, the speed of sound in air will change from 1129.5 ft/sec to 1161.3 ft/sec for the same temperature change. That's a speed increase of 28,154 ppm, and it causes the reflected wave to rebound from the bottom of the clarinet tube back to the reed in a shorter time, thus raising the pitch by 28,154 ppm. Thus the pitch change due to heating of air (28,154 ppm) is about 50 times greater than the pitch change due to wood expansion (560 ppm). Also, note that the expansion effect is to lower the pitch, whereas the speed of sound effect is to raise the pitch.

Furthermore, a simple calculation can allow one to determine the effect of these changes upon the pitch. If we are considering a specific pitch, say A=440 hz, then the next note in the even tempered scale will be A#=466.164 hz. That's a difference of 59,464 ppm in frequency. The thermal expansion change of 560 ppm makes the note about 560/29,463 or five hundredths of a semitone (5 cents) flatter. On the other hand, the pitch change due to the speed-of-sound effect is 28,154/59,463 or 47 cents -- almost a quarter tone -– from dead cold to fully warmed up. It's clear that the thermal expansion of materials like wood is a very small factor in terms of pitch. A change of five cents is of little practical consequence to a competent clarinetist.

On the other hand, small changes in the dimensions of a mouthpiece, especially if the lay changes due to thermal or moisture expansion across the grain, may cause significant changes in response. Unlike metals and synthetic materials, wood's dimensional changes are not the same in all directions (called "anisotropic"), thus the expansion may not only distort the size of the mouthpiece, but also its shape. Furthermore, some of these changes may be irreversible in the long term. Therefore it is fair to say that wood is a much less stable material many other materials and therefore less suitable for use in mouthpieces because of changes in mouthpiece response. But the facts do not support the idea that thermal expansion is the main cause of instability, nor that the pitch changes significantly when the temperature of a wood mouthpiece changes. It is interesting that wood is often criticized for thermal expansion. But ABS Delrin or acrylic, which also have relatively high thermal expansion values, are rarely if ever criticized on those grounds.

In fact, it has been reported (869) that the facing of wood mouthpieces changes constantly due to moisture content, etc, thus in the days before hard rubber, facing was a skill that students learned in conservatories. As one author put it, "You know how the orchestra waits patiently, while the concertmaster changes a violin string. Well, they waited also while the clarinetist fixed a warped facing in the middle of the concert." In addition, facing wood clarinet mouthpieces reportedly is a challenge because wood does not take the very fine adjustment necessary for a precise, good playing facing. (869) Also its long term stability ("tomorrow, or next week, or even 15 minutes from now when the moisture of your breath has soaked into it") causes changes. (869) It is said that Berlioz wrote in 1842 "If for any reason a clarinet were to remain for a few days without being played, or was in use for too long a time, dryness or humidity rendered the wooden mouthpiece difficult to use". (938) Regularly treating wooden mouthpieces with oil reportedly can make the wood less susceptible to absorbing moisture and thus improve stability. (5024)

Wooden mouthpieces are typically special-order high-cost items costing hundreds of dollars.

b. Bone and Ivory

Ivory was used before the development of modern polymeric materials. Ivory is reported to be about 70% of a ceramic called hydroxyapatite. (http://www.doitpoms.ac.uk/tlplib/bones/stem.php) This material is presumably less susceptible to wet/dry effects than wood. Also, as shown in the table, it's more stable thermally. It has been reported that ivory mouthpieces play with more resistance than wooden mouthpieces; the sound has a character with "depth and point"; and they respond slower. Ivory and bone mouthpieces are not seen today.

c. Hard rubber

"Hard rubber" also known as rubber-elastic material (REM) is a crosslinked polymeric material. Polymers are long chain molecules that have special properties (e.g. viscosity) due to their large size. Polymers occur in nature as fibers (e.g. silk, cotton, wool), as biological materials (e.g. protein, DNA, gelatin), and as rubbery sap from rubber trees. Polymers with specific properties can be made synthetically (e.g. nylon, polyester, acrylic).

When adjacent polymers chains in polymeric liquids or solids are connected together by a process called crosslinking, the polymer can no longer exist as a liquid, but is permanently converted to a solid or a gel. Think of it conceptually as a knotted rope hammock at the molecular level. Crosslinking can be observed in common everyday processes such as frying an egg. In that process, the white of the egg is a liquid until the heat causes a crosslinking reaction that converts it to a solid. Another example is spaghetti, which can be flexible when wet, but becomes rigid when dry due to crosslink formation during drying.

Crosslinked polymers form a solid REM that stretches and recovers when it’s above its “glass transition temperature” (Tg). Above that temperature the polymer is essentially melted but remains as an intact solid material due to its crosslinks. Not all crosslinked polymers have a Tg. For example, cotton has no Tg (even when crosslinked) because it decomposes and burns at a lower temperature than it melts. To form REM, a polymer must have Tg below its decomposition temperature. When a REM is below its Tg, it is “hard rubber”.

Several types of hard rubber have physical properties that are suitable for fabrication of mouthpieces. Basically, rubber can be supplied as pre-crosslinked rods (rod rubber) which can be machined into mouthpieces, or as bulk rubber can be molded into the mouthpiece shape, then cured (crosslinked) in that shape.

Rubber rods can be produced and cured very consistently, then machined into mouthpieces. In that case, care must be taken to keep the material cool during machining, or else it will heat and begin to distort its shape. (1461, 1462) On the other hand, mouthpieces can be formed by molding prior to crosslinking, then cured to stabilize the final shape. Molded rubber mouthpieces that are “post-cured” can have more mouthpiece-to-mouthpiece variability due to physical changes during the curing process.

In fact, hard rubber is more stable than wood in many ways, but if exposed to high temperatures near or above the REM’s Tg, tables and facings may permanently distort. This might happen for instance when left in the trunk of a car in the summer, or if heated in a machining or facing process. Another drawback of hard rubber is that it can develop offensive taste and/or odor if not properly cured.

Hard rubber mouthpiece material is known by many trade names such as Ebonite, Vulcanite, Steel Ebonite, Steelite, etc. Most types of hard rubber are very cheap, readily available, easy to work with, durable, easy to maintain, stable, resistant to effects of moisture and temperature. It is possible to tailor make the properties of hard rubber to a desired specification. This enables a mouthpiece manufacturer to adjust density, modulus (stiffness), which some believe contributes to a particular desired sound, response, and resistance. (see http://www.clarinetmouthpiece.com/nomenclature.asp and http://www.chadashclarinet.com/mouthpiece.htm)

In spite of the versatility of hard rubber, the mouthpiece market is so small and other markets are so large that rubber manufacturers do not produce a rubber specifically for clarinet mouthpieces. Therefore most mouthpieces are made from stock hard rubber that’s designed for multiple other end uses.

Hard rubber as delivered from the rubber manufacturer has a normal variation in properties, as does any product. One simple test for the consistency of hard rubber is to check the variation in hardness with a Durometer. (4130) More sophisticated tests include density, Tg, elemental analysis, Young’s modulus (stiffness) and the like. Rubber hardness and other properties are affected by many factors, such as sulfur (crosslink) content, curing time and temperature, etc. Getting the right properties is a matter of controlling the raw material (e.g. monomer, catalyst) as well as the process conditions, e.g. time and temperature. (4130) Some refacers claim that the softer batches produce the best sounding mouthpieces, but these are more difficult to face accurately. (4127) In the end, the goal is to control how the reed interacts with the hard rubber, as well as the short- and long-term stability of the mouthpiece. Long-term effects include discoloration, oxidation, warping, etc.

Needless to say, with advances in polymer chemistry during the 20th century, the typical hard rubber available today is a far cry from what was produced before 1960 when the "great vintage mouthpieces" (e.g. Kaspar, Chedeville) were made. Available raw material rubber has changed due to cost, safety and environmental regulations, large volume end-use requirements, new manufacturing technologies, and many other factors. Almost all rubber these days is manufactured to specifications other than clarinet mouthpieces. In fact, no specification for clarinet mouthpieces has been published. Such a specification would contain information like the density, Young's modulus (stiffness), Tg, hardness, and the like. Alternately a specification could include a recipe (monomer, catalyst, polymer, crosslinker, and other additives) and a process specification (time, temperature, pressure, etc). With two exceptions, it's doubtful that any general specification of either type exists at all specifically for clarinet mouthpieces, even as a proprietary trade secret (arrived at by considerable expense and experimentation). So, over time, the characteristics of mouthpieces made from hard rubber have gradually changed as the available raw material changed.

The two notable exceptions to the above are the mouthpieces of Brad Behn (http://www.clarinetmouthpiece.com/) and Chadash-Hill (http://www.chadashclarinet.com/mouthpiece.htm), which are reportedly made from customized prototype hard rubber that mimics the characteristics and properties of REM materials used in the early days of hard rubber technology. These are claimed to have special sound and response characteristics. But they have very high cost, undoubtedly due to the high cost of producing the prototype rubber material in relatively small quantities compared to commodity hard rubber that is normally produced, as well as extensive hand finishing.

Another approach has been reported in which materials (often called "hard rubber") are actually blends of plastic and ground-up hard rubber. (1461, 4118) The properties of these can be adjusted by varying the type and blend level of the materials in the blend. (4118) Some are reported to have as little as 10% rubber blended with plastic. Other reports say that some mouthpieces called "hard rubber" are actually plastic and contain no rubber at all. (4119) It can be difficult to tell the difference between hard rubber, plastic, and blends of the two. (4115) One method of differentiating between rubber and plastic is to observe the color and nature of the dust produced when facing the mouthpiece. It has been reported plastic mouthpieces sanded pink (Penzel Mueller), white (Runyon) or gray (Bari). But anything is possible. (4130) Hard rubber typically sands from light yellowish-tan (sulfur color) to an amber brown. (4130) Additionally, many plastic mouthpieces are made of acrylic materials which have a distinctive odor when sanded. Variations have been noted in older mouthpieces, which are said to be made of softer hard rubber. In some cases this softer material can be difficult to reface due to its softness. (4118) Whether this is due to a fundamentally different REM, or due to variation in REM/plastic blend level is not clear.

Certain Runyon mouthpieces have been described as being made from acrylic with a percentage of synthetic rubber (4120). It was further reported that type of rubber and blend contents are proprietary, and this blend material was designed to mimic the physical properties of high quality hard rubber. (4120)

Additionally, it has been reported that Gregory mouthpieces were made from a proprietary blend of plastic and hard rubber. (601)

The problem of predicting the playing characteristics of a mouthpiece from the properties of a material is formidable and has not been solved. Therefore any specifications as to material have been arrived at empirically, probably at great cost to the manufacturer. These are very unlikely to ever be disclosed, if it exists at all.

Hard rubber clarinet mouthpieces vary in retail price from $40 to over $700.

d. Plastic

Another synthetic material that is popular for clarinet mouthpieces is plastic. There are many types of plastic, but common types of plastic used for clarinet mouthpieces today include acrylic, ABS (acrilonitrile-butadiene-styrene), polycarbonate, and POM (polyoxymethylene).

Plastic differs from REM in its molecular makeup. REM is a crosslinked network of long (essentially two-dimensional) polymer chains with (very roughly) one crosslink between chains every 10 monomer units. In between the crosslinks, the polymer chains can move freely, above Tg. Plastic on the other hand is a three-dimensional polymer network where the individual polymer monomers have no chance for segmental motion at any temperature.

Acrylic and ABS plastic are used to make many very low-cost student mouthpieces, which can be purchased wholesale in large quantities typically for under $5 each, or retail for about $15. They can be molded, or they can be machined from rod stock. It is reported that the stock Buffet mouthpieces are acrylic, made by ESM in Germany. (4101) Acrylic mouthpieces are reportedly easy to reface and rework.

POM is sometimes used for higher quality plastic mouthpieces. Trade names for POM include Delrin, Kepital, Celcon, Hostaform and Ultraform. It's used for many purposes such as handles, gears in small devices, etc. It is reported to have vibrational characteristics very similar to hard rubber, and is available in the form of white or black rods. (1462) This material is tough and machines well. Also, it's approved for food use by the FDA.

It's reported that some Runyon mouthpiece models are machined from Delrin POM rod stock. (1465) It's also reported that clarinet barrels have been made from Delrin POM by instrument makers like Steve Fox. (1466, 1467) POM is an interesting material because apparently high-quality mouthpieces can be made from it at low cost, and it's easy to machine.

Polycarbonate is also used for clarinet mouthpieces, notably the Rico Grafonite series of low-cost mouthpieces which retail for around $15. (http://www.wwbw.com/Search.list?N=61&Ntt=graftonite http://www.ricoreeds.com/productdetails.aspx?productCategoryName=SaxophoneMouthpieces&productID=4071) (4102)

In general, plastic is regarded as a reasonable low-cost material for use in student mouthpieces that is not capable of producing quality of sound that hard rubber can produce. (http://www.clarinetmouthpiece.com/nomenclature.asp)

e. Glass and crystal

Glass mouthpieces are available from several manufacturers. While these are in the minority of mouthpieces in use today, they are not particularly rare.

Soda glass is a very hard and brittle material made from silica, to which various stabilizers and modifiers are added. When typically 20% to 30% lead oxide is added, the material is called crystal. The added lead replaces the calcium content of typical soda glasses to harden, stabilize and modify the glass. Of course, the term crystal is simply a descriptor of the appearance of lead glass. All glass, by definition, lacks any crystal structure. The addition of lead oxide to glass raises its refractive index, increases its sparkle appearance, and lowers its softening temperature and viscosity. The density of glass is naturally dependent upon the composition of the glass and varies widely, from less than 2.4 g/cc for soda glass to over 4.0 g/cc for lead glass. Lead can migrate from lead crystal into liquids with which they come in contact, especially for alcoholic or acidic liquids. I could find no reference that describes what this means in terms of crystal clarinet mouthpiece safety. Although this is not discussed in literature about mouthpieces, it's an important issue that deserves study, especially for younger players, who are more susceptible to the adverse health effects of lead exposure.

Glass mouthpieces are said to have unique behavior, with higher resistance and a "dark but colorful flute-like sound". To offset the higher resistance, softer reeds are reportedly preferred. (http://www.clarinetmouthpiece.com/nomenclature.asp) The higher resistance has been attributed to uneven or asymmetrical facings that reportedly are characteristic of glass mouthpieces. (4137) Thus the resistance differences between glass and other mouthpieces may be partially due to differences in designs or manufacturing practices, not necessarily due to the glass itself. It is reported that Obrien glass mouthpieces have deep table concavities and a deep baffle, which may be important to their sound (not just the glass material).

Nonetheless, glass is physically different than other mouthpiece materials in terms of stiffness and density, and this may (or may not) contribute to sound and response differences between glass and hard rubber mouthpieces. (4137)

Glass mouthpieces were somewhat more popular in the 1960's than they are today. Obrien and older Selmer glass mouthpieces are made from softer soda glass, whereas Pomarico and Vandoren crystal mouthpieces are a harder material. (4137)

Glass is very stable in the long term as it is not affected by moisture and it does not warp. Its thermal expansion coefficient is very low. Of course, the drawback to glass mouthpieces is the possibility of chipping or breaking them. They are also fairly expensive in general, with retail prices being typically $75 and up.

f. Ceramic

Ceramics are inorganic crystalline oxides which have many specific properties. They generally are very rigid, inert, hard, strong in compression, but weak in shearing and tension. Some are very brittle. They are resistant to chemical damage and generally can withstand very high temperatures. Glass isn't a ceramic because it has no crystal structure, but glass has many similarities to ceramic materials, especially in terms of its mechanical properties and behavior. The best known traditional ceramics are clay minerals such as kaolinite. Other ceramics include alumina (aluminium oxide). Modern ceramics include materials like silicon and tungsten carbide.

Like glass, ceramics are not easy to form into mouthpieces. There are very specific forming techniques which are well known, but a discussion of these is beyond the scope of this review. Certain non-crystalline ceramics (glasses) can be formed and then later heat-treated to cause partly crystallization, resulting in a "glass-ceramic".

One manufacturer of ceramic saxophone mouthpieces is Aaron Drake (170, http://www.drakeceramicmouthpieces.com/), who uses a porcelain ceramic material. This material reportedly produces a saxophone mouthpiece with quick, clear response, therefore facilitating articulation of fast staccato. Also, improved dynamic range and intonation stability is claimed. Ceramic mouthpieces are very resistant to dimensional changes and corrosion, since they do not absorb water. These are aluminum based ceramics that are heated above 1000°F to crystallize (or partially crystallize) them.

g. Metal

Considering the widespread acceptance of metal mouthpieces for saxophones, it's surprising that there are so few metal clarinet mouthpieces available. I am not aware of any really high-end mouthpieces made from metal, although one would think some enterprising entrepreneur would try to make one from some precious metal simply as a marketing gimmick. Published reports speculate that the reason for this is simply tradition. (93) It seems that classical clarinet players might reject a metal mouthpiece, if for no other reason than tradition. But even so, it's surprising that metal has not made inroads into the jazz, Dixieland and ethnic clarinet playing.

For saxophone mouthpieces, a base mouthpiece of brass, bronze or aluminum is typically plated with gold or silver. These reportedly have quick response and resonant sound, especially in high-baffle versions which produce a saxophone sound with added brightness and volume.

IV. Does material matter?

Keeping in mind the specific properties of materials commonly used in clarinet mouthpieces, let's look whether or not the material from which the mouthpiece is made really makes any difference. This is quite a question and if you're at a gathering of reed players and things start to get dull, you can always spark a very lively debate by simply starting up a discussion of whether or not the material that a mouthpiece (or instrument) is made from makes any difference?

Part of the difficulty in answering this question is that very slight physical variations between "identical" commercial clarinet mouthpieces produce significant differences. Additionally, sounds that may be of quite different quality may appear to have essentially identical waveforms when measured, even with the best equipment. Thus it's generally very difficult or impossible to settle this question by scientific experimentation.

That being the case, the evaluation of mouthpiece materials becomes subjective, rather than objective. This leads to all manner of folklore, misinterpretation and anecdotal information by well-meaning persons and by mouthpiece vendors who are trying to promote their own products.

Another difficulty that causes disagreements is the vagueness of the question. In other words, the question "Does clarinet mouthpiece material make any difference?" means quite different things to different people. Here are some alternative interpretations of the question. These variants can be seen in published comments, showing that different folks are actually answering different questions. Some examples follow.

1 Does material affect the sound that the player hears?
2 Does material affect the player's experience in non-audible ways, such as legato or staccato response, reeds, and/or playing effort/comfort?
3 Does material affect the sound that the listener hears?
4 Does material affect the mouthpiece response, making it easier or more difficult for the player to accomplish the desired effect?
5 Do certain materials hold their properties better than others as the mouthpiece ages, thus performing more consistently over time?
6 Are certain materials more workable, thus making it easier to consistently manufacture better quality mouthpieces more consistently?
7 Do high-cost materials cause players or manufacturers to have different attitudes about mouthpieces made from specific materials?
8 Do high-cost materials cause a manufacturer to take a different level of care in manufacturing mouthpieces from those materials?
… etc.

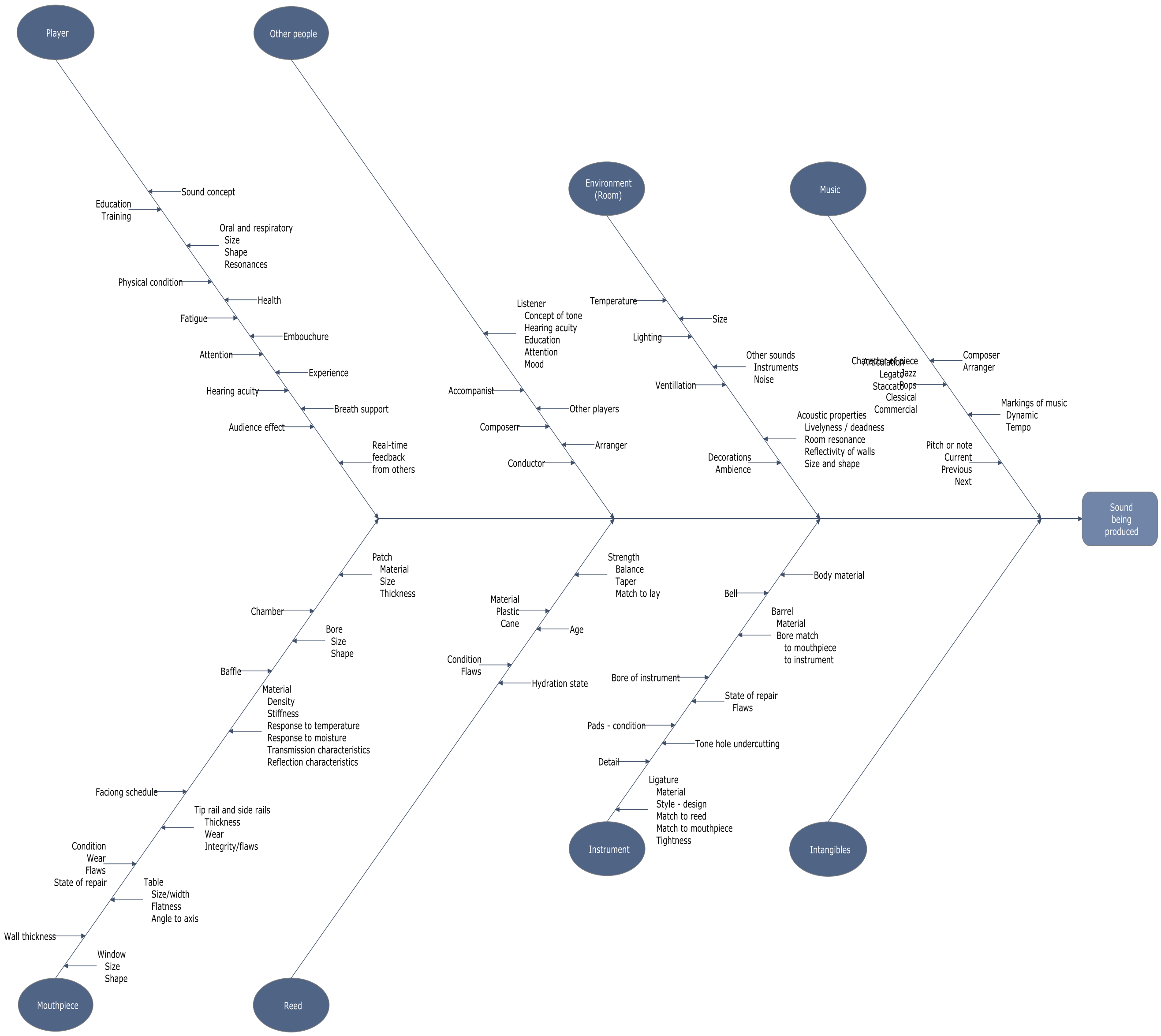
A case in point came out in a Mouthpiece Work Group website discussion. A saxophone mouthpiece manufacture's website claimed that material makes no difference to a mouthpiece's tone. But this manufacturer introduced a new line of gold-plated brass mouthpieces. When asked why, his reply was as follows. "Good catch -- that's true, I don't believe material affects the sound. However, a lot of people just like metal for its density, heaviness, and looks. It also makes a difference to the player, with the vibrations being conducted through the top teeth. It's just another option I want to make available to become a full range mouthpiece maker. I should include this in the faq on my page now. Thanks for making that observation. And the shape of the embouchure, since metal mpcs have such a smaller profile. I think it has been mentioned before that, even if you could compare a metal and HR mouthpiece with identical facings and interior dimensions, it is conceivable that the change in mouth position could change the sound more than any difference in material. Also (as I think Keith meant), it certainly changes the feel in the mouth - many players are only comfortable with one or the other. No doubt they could get used to the other material and exterior shape, but that intial weird feel of a different profile mouthpiece is often a deal-killer for them." (4468, 4471)

So the manufacturer's position was "I don't believe material affects the sound". But he goes on to say there might be effects in …

Customer reaction – some customers prefer metal
Better feel and appearance (density, heaviness and looks)
Transmission of vibrations to player's teeth (what the player hears)
Size fits some players embouchure better, giving better sound

a. <u>Clarinet sound quality</u>

Many factors influence the sound that's produced. To take a broad view of it, the following chart is explanatory. This is a "fishbone" or "Ishikawa diagram", named after its creator Kaoru Ishikawa. It systematically lists causes that can contribute to a specific result. (This can be copied and enlarged in order to see it better – also another listing follows.)



Looking at each individual cause of sound variation, you can realize that sound is influenced by many factors. Since the above fishbone is small and difficult to read, the list of factors is re-written below. In the list below, the colors signify:

Blue = items usually (or completely) under the player's control
Orange = items sometimes (or partially) under player's control sometimes
Black = items rarely or never under the players control

PLAYER

Sound concept	Training	Education
Skill	Physical condition	Embouchure
Fatigue	Motivation	Attention
Experience	Hearing acuity	Breath support

Real-time feedback from coach, instructor or audience

OTHER PEOPLE

- Listener (audience)
  - Sequential/simultaneous auditory effects
  - Education and expectations
  - Listener's concept of clarinet sound
  - Influence of other listeners/Audience
  - Mood
  - Real-time feedback (from coach, instructor or audience)
- Accompanist, and instrument being played by accompanist
- Instrumentation and other players (if any) in the ensemble
- Composer/arranger (music selection)

MOUTHPIECE

Facing schedule	Chamber	Baffle
Back bore	Material	Wear
Flaws	State of repair	Wall thickness

Table: Size, Angle to axis of instrument, flatness
Tip rail: Thickness, flaws/integrity, Flip
Side rails: Thickness, flaws/integrity
Patch: Material, size, thickness
Window: Size, shape, undercutting

REED

Material	Age	Condition	Hydration state
Strength	Balance	Taper	Match to mouthpiece

INSTRUMENT

Barrel Bell Ligature (Material, Tightness, Design)

- Clarinet Body (upper and lower joint)
  - Pad condition — Tightness
  - Tone holes (undercut) — Bore size
  - Bore configuration (polycylindrical, etc)
  - Condition / state or repair — Material
  - Wall thickness

ENVIRONEMENT (VENUE)

Light	Temperature	Size	Acoustic properties
Lively or dead	Resonance	Other objects in the area	

MUSIC

Composer/Arranger
Character of piece being played: Classical, Jazz, Commercial
Markings: Dynamic loudness of note, Tempo
Pitch: Current, Pitch previously played, Next pitch to be played

INTANGIBLES

Even for the same player, same clarinet, same set-up, same note, same dynamic, etc, the sound of a particular note may vary considerable for example between the following

Chamber music recital playing Gould "Benny's Gig"
Baermann Adagio played in church on Sunday morning
Premiere Rhapsody played for senior recital
Sousa march at an outdoor concert
Kletzmer
Clarinet lead in a big band sax section
Dixieland gig in a small nightclub
Brahms trio with cello and piano
Symphony orchestra performance

because the player's concept of desirable sound varies.

Which of the above is the single most important factor for the player? My vote goes to "sound concept" … in other words, what sound does the player desire to produce? The same set-up (instrument, barrel, bell, mouthpiece, ligature, reed, etc) played in the same venue by different players can produce vastly different results. But there are clearly many other factors as shown above. Some of these are under the player's control and others are not. Mouthpiece material is only one of many factors that might influence sound.

b. <u>Other thoughts</u>

Here are more of the many arguments that have been presented as to whether or not the material of a mouthpiece makes a difference. These have been paraphrased to save space. Reading these ideas may help you decide whether mouthpiece material makes any difference for you.

Manufacturers making cheap mouthpieces use cheap starting materials. Manufacturers of expensive mouthpieces -- experienced craftsman that put in dozens of hours hand-finishing a mouthpiece -- are not going to select cheap starting materials. They are going to select materials that are easier to work with, produce a higher quality and more durable product, and are aesthetically pleasing to the customer. Generally these mouthpieces are made of more expensive materials. Therefore there is an expected correlation between low cost materials (e.g. plastic) and low quality mouthpieces. That does not mean that a high quality mouthpiece couldn't be made from those same low-cost materials. But in commercial mouthpieces there is certainly a correlation between material type and mouthpiece quality.

The fact that the two things are correlated does not mean that they are cause and effect. It's a fact that the decline in birthrate in Europe since WWII correlates almost exactly with decline the Audubon society's stork population count. (Bruce Ames, *Carcinogens, Anticarcinogens and Risk Assessment*, 1972) But that does not prove that storks bring babies. It's a fact that the amount of corn grown in Kansas correlates almost exactly with the amount of cotton grown in Texas. (Cotton Incorporated, 1980, unpublished results) But that doesn't prove that corn causes cotton. It's also a fact that married men live about 5 years longer than unmarried men. But it's more likely that dying young causes men not to marry, rather than being single causes early death. So which is the cause, and which is the effect?

In the case of mouthpieces, a low-end mouthpiece manufacturer selects the cheapest useable materials available, i.e. acrylic or plastic. So the fact that it's a low-end mouthpiece with mediocre sound is the cause, and being made of cheap material (acrylic or plastic) is the effect. Not the other way around. On the other end of the scale, it's possible to make a low-end mouthpiece from high cost starting material, but nobody would do that (on purpose). A manufacturer of top-of-the-line mouthpieces selects higher quality (more expensive) raw material, because the main cost of a high end mouthpiece is in the hand-finishing. Raw material cost is relatively less important for top-of-the line mouthpieces than for low-end ones. So the correlation between material type and mouthpiece quality may (or may not) be cause-and-effect. And if it is cause-and-effect, which is the cause and which is the effect? Undoubtedly, it varies from manufacturer to manufacturer.

c. Some random left-over anecdotes

The following are some random left-over anecdotes that have been published. Although they did not fit into the previous presentation, they seem worth mentioning.

It may be that the inherent properties of the material cause it to be formed or produced better – for example, some believe that chrome plated Bonade ligatures do not sound as good as silver or gold plated. The chrome-plated version also tends to loosen and slip off of the mouthpiece more easily. This is a pain when changing rapidly between Bb and A clarinet. But if the internal section of the chrome ligature is roughed up with a Dremel tool brush, the sound improves significantly. The slippage and the sound become very similar for all three types. This is not due to the acoustic character of the material, but simply the fact that chrome plating makes a smoother and slicker surface than gold or silver, which affects the reed vibrations, therefore the sound. In this case, a smoother surface is not desirable, as it allows slippage.

In "The Art of Organ Building" volume I and II, George Audsley reported that wooden and metal pipes show different tonal characteristics according to the material used. The sound also depends on what proportion of the metal is tin, what proportion is lead, what proportion is another alloying compound. On the other hand, the type of wood, and the fineness of the grain matters. However, organ pipes are usually thin enough to resonate along with the air column. Where the material is thick enough to not resonate with the sound waves, the only sound effect reportedly is the frequency ranges that a particular material will absorb/reflect the best. (630)

As a corollary to the above, it has been reported that the material matters more in thin-walled saxophone mouthpieces for hard rubber mouthpieces. Rigid materials (e.g metal and glass) can be made into thinner walled mouthpieces, but saxophone mouthpieces made form less rigid materials (hard rubber) should have thicker walls. The smaller metal types allow the player to have a different oral cavity and respiratory tract configuration, thus a different sound.

An often quoted study from the 1971 *Journal of the Acoustical Society of America* was conducted by Dr. John Coltman, a physicist and researcher for the Westinghouse Electric Corporation. (http://www.bretpimentel.com/articles/wallmaterial.php) who tested the sound properties of flutes made from various wall materials while minimizing the effects of instrument variation, physiology, and psychology. He used three identical cylindrical tubes (silver, copper, blackwood) fitted with identical flute headjoints made of Delrin. The headjoints passed through a shield so the player could not see the flute body. All of this was mounted so that the player could not to touch any of the tubes, and rotated to bring each of the headjoints into playing position. The results showed that neither flutists nor listeners could accurately identify a difference in sound between the three materials. Many other studies, especially those by Backus (see http://iwk.mdw.ac.at/Forschung/english/linortner/linortner_e.htm) at the University of Southern California, confirm these results. But though the scientific evidence seems overwhelming, musicians still insist they can hear a difference. (637)

Comparing Quantum Delrin to Bronzite metal for two saxophone mouthpieces with identical internal dimensions, the Delrin model is a little more alive and vibrant whilst the Bronzite required more air to get it to sing and resonate. (609, 620, 617)

It is reported that a trumpet made of wood had a tone that could not be told from that of a brass trumpet when both were sounded behind a screen. (645)

V. Summary / Conclusions

Much has been published about mouthpiece material in general and clarinet mouthpiece materials in particular.

Commercial clarinet mouthpieces are made from various materials of widely differing properties, specifically wood, bone/ivory, hard rubber, plastic, glass/crystal, ceramic and metal. These materials vary in many important respects such as durability, cost, ease of manufacturing, and aesthetics. The choice of material is an important factor in the mouthpiece’s cost, durability, appearance and maintenance requirements.

In terms of clarinet sound, there is a wide range of opinions. Generally it’s agreed that there are many factors influencing the clarinet sound (see page 16) that are far more important than the choice of mouthpiece material. Some of these factors are within the players control and others are outside of the player’s control. Skilled players achieve excellent results on mouthpieces made from vastly different materials.

So far I tried to present facts without giving any opinions. I know that I probably was not 100% true to that goal, but I tried to be fair to all points of view. Where there has been consensus, I presented the consensus. Where there is not any consensus, I tried to present both sides. Now the next paragraph is definitely an opinion.

If a player plays a type of music that demands a certain specific sound or effect (response, legato, staccato, etc), and if that player has achieved excellent control of the controllable factors, then evaluating mouthpieces made from various materials might make sense. Those are two pretty big “ifs”. On the other hand, a player that has not accomplished control of the controllable factors is very unlikely to achieve much by searching for the perfect mouthpiece material. This is not to say that mouthpiece materials do not matter to the sound, it’s just that the subtle differences are not very important until after a player has mastered control of most important main factors controlling sound. Also, if you are getting a poor sound and want to upgrade your sound to be just like Harold Wright (or whoever your favorite player is), my opinion is that you won’t get very far toward that goal by going out and purchasing the same kind of mouthpiece he plays, unless you have first mastered many other factors that contribute to a good sound.

Finally, I recall an anecdote about “how to select the perfect mouthpiece”. It says essentially the same thing as above in another way. I don’t remember where I read it, but it goes like this …

How select a perfect mouthpiece …

(1) Gather up all your mouthpieces
(2) Put them in a box
(3) Go to the beach
(4) Put on a blindfold
(5) Pick out one mouthpiece at random from the box
(6) Throw the rest of the mouthpieces into the ocean
(7) Go home and learn to play the mouthpiece you selected

Good luck.