



THE ORTHODONTIC MATERIALS  
**INSIDER**  
ORTHO-CYCLE

A quarterly dedicated to **orthodontic professionals**, and to the renewal of their habits and tools by **ORTHO-CYCLE CO.**, A COMPANY WHICH RECONDITIONS, BUYS AND SELLS ORTHODONTIC APPLIANCES.

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## Why have information on orthodontic materials ?

“Every craftsman should know well his tools, even though they may be words” (H. de Balzac, 1799-1850)

“No one will be able to learn a thing if he is convinced that he already knows it” (Socrates, 469-439 B.C.)

Started in 1987 as a newsletter attempting to establish recycling to the profession, “Phoenix Without Ashes” has become a sort of consumer report, a reliable and at the same time popular source of information for the practicing orthodontist. The significance of its name has become practically forgotten, only relatively few of today’s readers remembering its original meaning. This was revealed by the answers to the quiz presented in our last issue, the best of which are shown on page 7. While the initial purpose has faded, attachment recycling being by now well received and recognized, the unbiased presentation of the different materials used by orthodontists has been received with interest by thousands, being praised by many luminaries.

The average orthodontist gets his information from his school, journals, meetings and...salesmen. In most cases, the information available is either scarce, not objective or limited to particular investigation interests. On the other hand, there are thousands of products to choose from, a real embarrassment of riches. There are many academic capabilities, but, to quote two U.S. government publications<sup>1,2</sup>, there is a general lack of interest in performance-oriented research as being “too macroscopic<sup>1</sup> or “not fundamental enough”. According to one study<sup>1</sup>, only in the last 25 years, and especially in the last decade, has the foundation of what we call materials science begun to take shape and to achieve recognition. The advancement achieved in our times can be better understood with the help of a few examples. To suspend a 25-ton weight vertically from the end of a cast iron rod (the strongest material available at the beginning of the last century) requires a rod with a cross section of 1”x1” weighing about 41b/ft. A modern polymer fiber, however, requires only a rope with a cross section of 0.3”x 0.3” yet weighs about 1 oz/ft. Another polymeric fiber, poly (paraphenylene terephthalamide), was found

to have a tensile strength higher than that of a steel fiber of the same dimensions, yet weighing only a fifth as much. As a result, materials scientists are at the forefront of all the areas of science in the service of society.

In orthodontics, the speed with which new materials are picked up by the orthodontic suppliers has multiplied several times within less than a century. Compare the time elapsed since the discovery of stain-less steel (Maurer, 1912), till its use by Angle (1930), or with that of superelastic alloys (Buehler, 1961) till their use in archwires (Andreasen, 1971). Furthermore, compare the few years elapsed between the commercial re-lease of partially stabilized zirconia (Imperial Chemical Industries, 1985) and its use in direct bonding brackets (Lee, 1990). Recently, even this interval has shrunk: consider the time elapsed between the development of diamond-like carbon coating through plasma source ion implantation and its application to improve brackets...

Independent and reliable information must be conveyed to the practitioner as fast as possible, preferably long before the release of the new materials (like a radio traffic report, it has to come early enough to allow you to change your route: if you are already stuck in the backup, it becomes useless). The lack of interest in manufacturing and product information may result in thousands of wasted dollars, hours of additional chair time, or even in lost court battles.

Although orthodontic materials manufacturers have succeeded in bringing forth a variety of superior materials, not all had the patience to wait for years of clinical use **before** launching their products. Cases in point include the detachment *en masse* of some direct bonding brackets from their bases due to poor brazing, the leaking of nickel from corrosion susceptible attachments or the abrasion or **fracture** of enamel by ceramic brackets, to **name** only a few.

An honest presentation of the problems raised by new materials, instead of the ubiquitous and pervasive hype, may actually bring more understanding, interest and cooperation between manufacturers and practitioners. As the need to extol attachment recycling has become almost obsolete, by now almost all the orthodontists having an opinion of it, "Phoenix Without Ashes" has

gradually changed, focusing toward orthodontic materials. To better reflect its new content, the "Phoenix" is now reborn as "The Orthodontic Materials Insider". The need for unbiased information on orthodontic materials has become too stringent to ignore the demand, especially now, when it has been predicted that in only five years, half of what we will use, may be new...

## Why "Materials in Orthodontics" and not "in Dentistry" ?

For almost twenty years, Ortho-Cycle's person-nel has been exposed to the successes and problems faced by orthodontists, people to whom it is strongly attached. It was our business to become "connoisseurs" and "insiders" in the orthodontic materials industry. Relating facts and opinions in our newsletter, we soon became amazed to see that we are actually filling a gap of which few were aware. Indeed, the problems raised by orthodontic materials are only to some extent the same as those of dental materials in general. In several instances, like in the case of the wires, they deserve an extensive and at the same time differentiated approach. Highly dependent on sophisticated materials, orthodontists use relatively few categories, but in an incredible variety. To give an example, there are today hundreds of thousands of different types of direct bonding brackets...

*From contacts with my orthodontists friends, and reading your newsletter, I am impressed with what you have accomplished, and congratulate you for your efforts. Your and our activities appear to have many similarities.*

**Gordon J. Christensen,  
DDS, MSB, PhD**

At the Northeastern Society of Orthodontists annual meeting of December 1994 in New York, we provided to more than twenty exclusive practicing orthodontists, a list of articles taken from the index of a very recent book on dental materials<sup>3</sup>. We asked them to mark from 0 to 10 the extent of each usage. Among metallic materials, brackets, bands, tubes, wires, coils, springs, clasps and forming pliers were all marked from 8 to 10, and so were the adhesives and elastics among polymers. The majority of the other materials listed, to which about 95% of the pages were dedicated, were marked with 0. Specific preferences were obvious even in the field of impression materials, where only alginates were selected. This not only shows the clear difference between the materials the orthodontist and the dentist use, but also the disproportionate attention given to dentistry to the detriment of its first specialty, orthodontics.

Dentistry is fortunate to have Gordon J. Christensen, who along his wife Rella, started in 1976, Clinical Research Associates in Provo, Utah. Today, CRA is an international organization counting more than 380

clinicians and 43 on-site basic scientists and staff, all dedicated to evaluate dental, but not orthodontic materials. He and his group are continuously lecturing, researching and publishing. There is almost no issue of J.A.D.A. without one of their contributions, and the CRA newsletter is widely read. Just as CRA evaluates dental materials and offers new vistas, we would love to be able to offer the same service to orthodontists. It is true, our organization is small, lacks clinical expertise and... provides commercial services. But being committed to attachment re-use and not to a manufacture, we think that we are the next best thing. Indeed, threatened with suits in court by most major manufacturers, we can afford to provide an impartial reporting, which is coming from people experienced enough to cope with the task.

In this first issue of our refocused newsletter, we would like to help the orthodontist realize that what we are doing is of concern to him. Sooner or later, chances are that he will have to take decisions in topics already analyzed by us. To see what is in store, it may be instructive to look at what came to light in the past few years. In the following pages, instead of quoting easily accessible references, we will present research published in journals less known to orthodontists, as well as recent patents. The topics selected focus on metals, polymers and ceramics, the building blocks of orthodontic materials, as well as on their composites.

## References

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## BREAKTHROUGHS ARE ALREADY HERE, OR EXPECTED SOON.

### METALS

#### General development

The introduction of a new decarburization process (argon-oxygen) starting in the 70's has allowed the precise control of the individual elements in stainless steels. This has made it possible to optimize performances by producing "materials by design", metals alone, in different states and in combination with ceramics. Thus, very fine grained, single-phase materials have shown excellent combinations of strength, ductility, and corrosion resistance. Finely interspersed phases, like those found in micro-duplex alloys, lead to high hardness and a better stability at higher temperatures. Chemically intercombined metals (intermetallic compounds) have superior qualities in higher temperatures and load bearing applications. Alien metals, which are intentionally dispersed into alloys, can act like obstacles in the way of the grain dislocations, movements which would otherwise lead to an excessive sliding of the steel layers under stress. The workhorse of today's "mini" brackets, designated as PH 17-4 (Precipitation Hardening, i.e. dispersion strengthened), owes its hardness to added metals like Cu, Nb. This toughness doesn't come without a price: the last stainless steel is more corrosion prone, as a result of its poorer homogeneity.

The era of metal composites has only recently begun, and thin films and layered structures (even as far as atom-by-atom layering) have already brought unique properties. Among these is the control of magnetic surfaces and interfaces, capability which leads to the new, artificial magnetic materials known as multilayers and superlattices. The complex coupling between the different magnetic layers is the base for large anisotropies and coercivities, properties not yet available in bulk materials. Even a whole new class of magnetic materials has been recently identified, the spin glasses. Their apparently random magnetic interactions lead to complex magnetic behavior unlike any known in standard ferromagnets and antiferromagnets, opening the way to a better understanding of magnetism.

#### Applications in orthodontics

**Alloys for attachments.** After about sixty-five years since the introduction of stainless steels in orthodontics, two superior types are entering the scene. Both are lower in nickel, metal known as allergenic and harmful to the tissues. The first, a stainless steel belonging to the "super steels"<sup>1</sup>, designated as UNS S31803 and better known as 2205 (22% Cr, 5% Ni) offers, if properly heat treated, a superior corrosion resistance and toughness. The above mentioned duplex supersteel has been introduced in bracket manufacturing by CEOSA, Madrid, Spain. Such duplex steels require a better understanding of their metallurgy in order to avoid embrittlement phenomena and the formation of an undesirable sigma phase that could take place during processing and

fabrication. Another type of steel, the so called "superferritic" one, has an even lower proportion of nickel and has been selected by Pyramid Orthodontics, San Marcos, CA. for their injection molded, one piece "Prestige" brackets. A steel belonging to this class, UNS 44800, known as 29-4-2, or ASTM A-268, has 2% Ni, and an increased amount of molybdenum instead (4%), while another one (E-Brite, Allegheny Ludlum) or UNS 44627 or 26-1) has practically no nickel in it (25-27.5% Cr, 0.75-1.5% Mo, 0.15% Ni, 0.02% Cu, 0.05% Mn). Both steels require a very low carbon and nitrogen content (under .005%) in order to insure adequate mechanical and chemical properties.

Titanium and its alloys are likewise interesting candidates to replace stainless steels in bracket manufacturing<sup>2</sup>. Thus, the so called ASTM Grade 7 titanium, i.e. titanium plus 0.12 to 0.25% palladium, is known to be the most resistant metal commercially available, being able to service in HCl, H<sub>2</sub>SO<sub>4</sub> and their hot, low pH salt solutions.

It is important to call the attention to the fact that the cases of bracket corrosion are accumulating, and that the industry is already preparing for the possibility that soon, the American and German supported Dentistry Technical Committee (TC106) of the International Organization for Standardization (ISO) will recommend only low-nickel alloys for continuous oral use.

**Superelastic alloys.** Departing somewhat from the equimolecular composition of Ni-Ti, additions of copper were found to allow an easier engagement of the archwire and to deliver higher forces<sup>3</sup>. Likewise, an addition of up to 5% in carbon is claimed to allow the control of the archwire springback properties<sup>4</sup>.

Still based upon the early findings on shape-memory/superelastic phenomena<sup>5</sup>, new applications are developing fast. Thus, with the goal to reduce the chair time, a differentiated thermal treatment along the archwire has been recommended<sup>6</sup>. By varying the radius along the arch, it is possible thus to obtain a more adequate and efficient configuration<sup>7</sup>. Multi-strand, braided archwires made of these alloys have been found to be more resilient, i.e. return faster and more accurately to the desired shape<sup>8</sup>. Likewise, the use of the same alloys to make coil springs is claimed to allow a higher deflection. A recent article<sup>9</sup> dispels the claim that the slopes of the loading and unloading plateau values can be significantly different from a brand to another, when using the same alloy. This may suit well the conservative orthodontist...

Shape-memory alloys have been suggested also for the manufacture of palatal or expansion arches<sup>10</sup>, for lingual and even complex removable appliances. In order to shape them at will in intricate forms, the wires are either heated in a deformable stainless steel tube<sup>11</sup>, or in several stages<sup>12</sup>. Interesting to mention is that instead of complicated furnaces, the direct application of an electrical current can also be successfully used.

The application of shape-memory alloys has been extended even to the manufacture of direct bonding brackets: at mouth temperature, the upper part of the slot contracts, locking the archwire<sup>13</sup>. The resulting retention may soon render unnecessary the existence of the tie wings". (Provided that the patient doesn't drink cold beverages!?)

**Magnets.** The attempts to copy nature are still far from being as successful as some bacteria, which are able to grow and properly orient molecules of  $\text{Fe}_3\text{O}_4$ , generating magnets. As shown in a past article<sup>15</sup>, however, the "energy product" ( $\text{BH}_{\text{Max}}$ ) of modern magnets has multiplied by four times in less than a quarter of a century

In orthodontics, the use of magnets is still at its beginning stages, but steadily growing, both in fixed and functional appliances (very likely as the result of series of patents of A. Blechman<sup>16</sup>, T.G. Noble<sup>17</sup> and J.E. Nelson<sup>18</sup>). Thus, a series of refinements are now claimed by Blechman alone<sup>19</sup>, some being based upon his older patents with H. Smiley<sup>20</sup> or with E.A. Pescatore<sup>21</sup>. Other patents in the field were awarded to A.D. Vardimon<sup>22</sup>, J.A. Collins<sup>23</sup> and T. Kawata<sup>24</sup>

**Processing and treatments.** Just when we thought that we have seen them all, the manufacturing processes used to make orthodontic attachments have gained another one. Aside milling, casting and sintering (injection molding), brackets can now be made by brazing together several preformed sheets, leading to a laminated, complex structure<sup>25</sup>, claimed to be easier to manufacture. We wonder how such brackets will behave, when the highly undesirable galvanic corrosion at the interface stainless steel/brazing will be multiplied... Indeed, years ago, after the failure of many silver-based brazings in joining brackets with bases, several manufacturers have switched to nobler, gold-based alloys. As even these are not satisfactory, nobler alloys are now proposed. Thus, an alloy having some 90% palladium was recently suggested<sup>26</sup>. Like the gold-based alloys, this should still lead to an accelerated galvanic corrosion of the steel with the corresponding release of Ni in the body.

"Individualized treatments" on each bracket may have achieved new heights with a permanent marking patented by Dentaurem. The marking is performed on a thin remelt layer, which is claimed to resist repeated recycling<sup>27</sup>. Shot-peening of metallic surfaces, introduced in bracket manufacturing by GAC for their Microloc<sup>®</sup> retention system<sup>28</sup>, is known to plastically deform the metal surface, improving corrosion resistance. Recently, the process has been successfully applied to impart fatigue resistance to other devices made of stainless steels, Co-Cr and Ni-Ti alloys<sup>29</sup>, all widely used in orthodontics. The need is there, for many instruments, brackets, tubes, etc. are made today through powder-metallurgy, known to lead to a less dense structure. In such instances, shot-peening may be used to generate

a closure of the outer pores and a strain-hardening of the respective rough surfaces.

Early in their development, metal brackets were varnish-coated to better blend with the enamel and withstand corrosion. The approach has re-surfaced recently, when two different types of coatings have been suggested. Thus, a diamond-like carbon (DLC) layer already used to increase the wear resistance of cutting tools (Balzers Tool Coating, N. Tonawanda, NY) is claimed to form on metal brackets a barrier against the Ni and Cr ions, protecting thus patients against allergies<sup>30</sup>. Interesting to mention, this type of very hard coating, made possible by new developments in the deposition of carbon at lower temperatures and pressures, is claimed not to increase the friction between the archwire and slot<sup>31</sup>, but actually to decrease it!

The use of another hard coating, titanium nitride (TiN), is expanding both for tools and brackets. A new, low temperature method (300°F) called Hyper-Ion (ISM Technologies, San Diego, CA) leads to coatings which are not only as hard as the ones produced by vapor deposition at higher temperatures, but much more adherent. Indeed, the corrosion behavior of the substrates coated with TiN has been found to be heavily dependent on the homogeneity of this layer<sup>32</sup>. Both progresses made in diamond-like carbon and titanium nitride coatings are due to plasma source ion implantation (PSI), a process developed at Hughes Aircraft and Los Alamos National Laboratory<sup>33</sup>.

To enable metallic bases to bond well without having a mesh laminated to the pad, several alternatives were proposed. In one of these, the base is joined to a myriad of tiny metal spheres which are in turn joined to each other, or sintered<sup>34</sup>. Another method recommends thermally spraying the base with molten metal<sup>35</sup>. But the most interesting method seems to be, as foreseen years ago<sup>36</sup>, the generation of micro-roughness by chemical means. Thus, a recent patent discloses an interesting property of an alloy made of Ni, Be, Cr. When cooled from molten state, this alloy leads to a dendritic structure of beryllium oxide, which, after acid wash, leads to a rough surface appropriate for bonding<sup>37</sup>.

**Metal/polymer composites.** A new technique, developed by Phillip Fan at Union Carbide Chemicals and Plastics Co., Bound Brook, NJ, bonds a lubricating coating to plastic or metal medical devices. When dry, the surface of the treated instruments feels as expected. When wet, it becomes very slippery and pleasing to touch due both the hydration and swelling of a polyacrylic acid component bonded to their surface. The coating resists autoclaving, and decreases the patient's apprehension toward treatment.

To reduce the friction exerted at the archwire interfaces, W.J. Kottmann had suggested to coextrude the metal wires with polysulfones<sup>38</sup>: the idea has been extended since by L. Adell to other plastics<sup>39</sup>. A simpler

method, coating, seems to work as well\*.

**Metal/ceramics composites.** The incorporation of ceramic fibers (alumina, silicon, tantalum carbide, etc.) in metals has been known to considerably toughen them. The surface of metals can be likewise made more resistant not only if coated with diamond or titanium nitride, but also with ceramics. Thus, A<sup>n</sup>-Co. has patented two such composites, one being a layer of porcelain fused on the bracket metal<sup>41</sup>, and the other a metal pad for alumina (sapphire) brackets<sup>42</sup>.

Alumina brackets exhibit a high coefficient of friction; to lower it, and improve at the same time their mechanical resistance, it was suggested to line their slots with metals, which can be brazed there with Pt, Ag, or an alloy of Mo and Mn<sup>43</sup>.

## ORGANIC POLYMERS

### General development

Organic polymers are natural allies of medicine because they enter in the composition of living tissues. As our knowledge advances, our ability to tailor polymeric structures imitating nature grows, implicitly increasing our power to heal. Subsequently, in spite of the litigious era in which we live, the progress in finding the factors controlling biocompatibility will continue...

Having high strength and flexibility along with light weight and superior optical properties, polymers have emerged from inexpensive commodity materials to value-added, high technology products capable of providing advanced performances.

Once more, the attempts to imitate nature pay: recently, Cognis Inc. (Santa Rosa, CA) has synthesized, with the help of microorganisms, monomers used in composite materials. In industry, polymer fibers are replacing metals, and adhesives are replacing rivets in many joining applications. In bio-engineering, the polymers have to be non-degradable (long-term functionality, sterilizability, hydrolytic stability), compatible with the biological materials (lack of mutagenic or carcinogenic properties) and...microbe resistant. To respond to such needs, new polymers are continuously synthesized.

Today, only in relatively few instances polymers are used alone, composites exhibiting usually better properties. The latter are hybrid creations made of two or more materials that maintain their identities when combined. The materials are so chosen that the properties of one constituent compensate the deficient properties of the other. Some-times, however, the property of a composite is dramatically better than that of either of the constituents (synergism). Thus, due to their high ratio length/diameter, long, continuous fibers have been found to afford a better control over the internal structure of a composite. By replacing as reinforcing phases common particles with whiskers or fibers, higher performance composites are obtained. As expected, the nature of the filler plays a major role, as demonstrated by the recent use of high-tensile-strength polyethylene fibers.

The interfaces within composites are equally impor-

tant, and the related defects or weaknesses can severely limit performances. As a result, methods for better joining the ingredients and the composites to other materials are re-searched. Indeed, if the properties of the joining material do not equal those of the composite, there may not be advantages in using the combination.

A different approach to achieve composite strength is based upon a technique borrowed from metallurgy. If softer materials, like elastomers, are added to rigid and brittle polymers, a toughening takes place. The process is similar to the precipitation hardening of the metals, already presented. Strangely enough, also the reverse works: the dispersion of rigid backbone molecules in a matrix of flexible polymer with the help of the so called "molecular mixing"<sup>1</sup> leads to composites which not only exhibit superior impact resistance and compressive strength, but also retain their optical properties. Notably enough, the analogy between blending in polymers and alloying metals is such that scientists studying macromolecules are learning now from the long experience of the metallurgists.

### Applications in orthodontics

**Monomers and polymers.** "Bowen's resin", bis-GMA, has remained the base, after almost forty years, of most dental composites, including orthodontic adhesives. Unfortunately, the resulting composites exhibit a coefficient of thermal expansion higher than that of the tooth, as well as some shrinkage during hardening. Due to its high viscosity, bis-GMA, a large molecule, has to be compounded almost half of its weight with lower, polyfunctional (meth)acrylates which contract too much during polymerization. (Almost all polymerizations occur with a contraction in volume, which is the greater as the monomer molecule is smaller). In some degree, this undesirable contraction can be reduced by replacing up to 80% of the resin with inorganic, inert fillers. To better compensate for this hardening shrinkage, new resins which expand in volume when polymerized are investigated at ADA's Paffenbarger Research Center, under the supervision of Bowen himself. Unfortunately, resins which expand (cyclic monomers which suffer a ring opening before polymerizing) are difficult to be made to comply with today's sophisticated demands for dental monomers. If successful, the resulting composites will have less gaps, fill cavities, stop marginal leakages as well as the intrusion of biological fluids with the microbes they contain. At the same center, a new redox initiation system has been found. Instead of a sudden, short-lived burst of free radicals, these are provided over a longer period of time, solving the problem of unpolymerized adhesive under bracket bases. Another advance in a related field made at this important center for the development of dental materials is the addition to acrylates of moieties that provide affinity for water, rendering them bondable even in wet conditions<sup>44</sup>.

A departure from the classic "Bowen resin" has been recently described by K.W. M. Davy<sup>45</sup>. The aromatic dimethacrylate esters proposed have a lower viscosity than bis-GMA and are, at the same time, X-ray opaques. Another

resin, belonging to the already commercial acrylate-capped polyurethanes, has been recently claimed to lead to tougher products which photo-polymerize faster<sup>1\*</sup>.

For general dental purposes, polyether-etherketone (PEEK), a thermoplastic polymer supplied by Imperial Chemical Industries, UK, may soon replace Delrin or similar plastics, being both resistant to heat (482°F continuous-use rating), as well as to moisture and chemicals.

**Processing and treatments.** Whenever polymers have to interface with other materials, difficulties usually arise. Irradiations, plasma and chemical etching, to name a few, are commonly used to solve the problem. To improve the poor bonding capabilities of the polycarbonates, inter-mediate layers of polymers like epoxies, urethanes & acrylates have been recently suggested<sup>\*7</sup>.

Among the few new refinements in the application of the composites used is the pre-coating of the brackets with light curable adhesive precursors (APC). The advance is based upon earlier works of Unitek<sup>48</sup> and the Japan Institute of Advanced Dentistry<sup>49</sup>. The resins used in the Unitek's new system are a mixture of the well-known bis-GMA with an ethoxylated bisphenol A-dimethacrylate<sup>50</sup>.

**Polymer/mineral composites.** Today's dental composites, usually an inorganic phase dispersed into a poly-meric network, are inferior to those found in nature (teeth, bones, sea shells). While in restoratives mineral fillers are only up to 80%, in nature these can go as high as 96%. On the other hand, synthetic composites have an anisotropic, homogeneous structure, while the natural ones exhibit a directional and subtle gradation of composition and properties, allowing them to achieve higher performances. (The shell of the tough to crack a macademia nut is made of relatively weak cellulose fibers, the orientation of which, however, reaches an optimum).

While dental composites (fillings, restoratives, veneers, adhesives) have remained almost unchanged since Bowen's findings, being inorganic minerals or glasses evenly dispersed into thermoset acrylics, attempts are made to align these according to their maximum resistance. This may allow the beneficial use of softer fillers: after years of using only hard fillers as oxides or silicates (the Mohs hardness for alumina is 9, vs. 4.5 - 5 for tooth enamel), a new trend can be observed. As minerals with a hardness under Shave been found to be acceptable as fillers for adhesives<sup>51</sup>, their application becomes interesting. Indeed, these can release beneficial ions, like F<sup>-</sup> for topical fluoridation<sup>52</sup>, or Ca<sup>2+</sup> and PO<sup>4</sup> for tooth remineralization<sup>53</sup>. The last ions, if slowly released from a composite containing an amorphous calcium phosphate, can be used to heal damaged tooth structures.

Silicates, especially if properly shaped in fibres like E-glass, can be successfully used to reinforce thermoplastic polycarbonate resins. If annealed, such composites can be used in splints, retainers, space maintainers and even in orthodontic wires. As a difference from metal archwires, these are aesthetic, can provide a con-

tinuous range of stiffness without changing their cross-sectional dimensions<sup>54</sup> and can have both their stiffness and strength characteristics customized". Non-metal, composite archwires are already sold by Ormco under the trade name Optiflex.

**Polymer/organic fillers composites.** The inclusion of untreated ultra-high-strength polyethylene fibers can increase significantly the impact strength of poly(methyl methacrylate)<sup>56</sup>. A similar, plasma-treated fibre may find a large use in improving the fracture toughness of the common poly(methyl methacrylate)<sup>57</sup>, as used in plates or prostheses.

**Elastomers.** Once more, after attempting other ways, modern chemistry had to return to imitate nature. Indeed, rubber-like elasticity arises from flexible chains interconnecting the crosslinked ones. Unfortunately, this property is partly lost when using the work-horses of today's force modules, the thermoset polyurethanes. Soon to be expected are the thermoplastic elastomers, which should exhibit a by far higher efficiency in storing elastic energy.

Aside from minor improvements, like the addition of flavoring substances<sup>58</sup>, an important change may come from the replacement of some of the carbon atoms from the elastomers chain through elements like Si, P, N. Thus, polysiloxane and polysilane elastomers are not only highly versatile, but exhibit also superior performances: the less carbon in the molecule, the more resistant to chemical attack (and staining) the elastomer<sup>59</sup>.

## CERAMICS

### General development

Not so many years ago, ceramics processing comprised the separation, crushing and then sintering of naturally occurring minerals. Today, many are synthesized from pure chemicals by vapor processing, aqueous precipitation or complex gel techniques. Sophisticated methods like melt processing, melt alloying and refinement followed by rapid solidification are widely used. The hot isostatic pressing, forging and extrusion of ceramics are now quite common. Oriented grains or crystals, low-dislocation or even dislocation-free single crystals are directly grown from melt, pushing to the extreme the oldest man-made materials.

The appeal of ceramics as is easy to understand: in spite of being light, their compressive strength may exceed that of metals. Exceptionally hard and resistant to abrasion, ceramics are also chemically inert. Two properties are still sought: fracture toughness and ease in processing. To achieve the first goal, it is imperative either to eliminate defects - the voids, agglomerations and impurities from which cracks originate - or toughen them by devising ways to prevent cracks from spreading. Fortunately, tetragonal zirconia, a material with future in the manufacture of direct bonding brackets, lends itself to the so called transformation toughening. As a crack starts to grow in such a ceramic, its tetragonal structure becomes monoclinic, with a resulting volume change of 3-5% that arrests crack growth. As a result, toughness increases fifteenfold.

There are also other ways of improving toughness, which involve achieving and maintaining very small grain sizes within the ceramic body, incorporating controlled and dispersed voids, or synthesizing ceramic-ceramic composites.

To improve flaw detection and avoid the release of fragile ceramic brackets, nondestructive methods (e.g. X-ray tomography, ultrasound) are now either currently used or investigated.

### Applications in orthodontics

Most ceramic brackets are made today from alumina, either by drawing, in profiled metal tubes, bars from a melt (like "A"-Co.'s "single crystal", "Starfire"<sup>®</sup> brackets<sup>60</sup>), or by pressing under heat its powders (like the polycrystalline Transcend<sup>®</sup> brackets by Unitek/3M<sup>61</sup>). As both procedures lead to brittle attachments, there are efforts either to replace alumina altogether, or to reduce its intrinsic porosity<sup>62</sup>. The most promising re-placement seems to be, as we have foreseen years ago<sup>63</sup>, partially stabilized zirconia (ZrO<sub>2</sub>/Y<sub>2</sub>O<sub>3</sub>). Recent advances at Lockheed, Palo Alto, CA, have led to the its "superplastic forming", a highly precise process where no machining is involved. Key are the nanocrystalline zirconia particles, whose diameters are measured in billionths of a meter. Some four years ago, Brian Lee from Australia has launched, with the help of Imperial Chemical Industries, the first partially stabilized zirconia brackets, a combination edgewise-Begg ("Free Form")<sup>64</sup>. A similar ceramic has been later claimed in France<sup>65</sup>. The

resulting brackets are less brittle, instead opaque and ivory colored. Their hue is due to certain metal oxides which can be either added purposely<sup>66</sup>, or removed to bring transparency. The otherwise too high, almost unpleasant light transmittance of alumina (100%), can thus be controlled with the help of strictly controlled additions of magnesium oxide (MgO)<sup>73</sup>. Through such refinements, zirconia, yttria and strontium titanate can be made not only more resistant to fracturing and chipping<sup>67</sup> but also clear<sup>68</sup>. The addition to zirconia of titanium dioxide<sup>69</sup>, aluminum oxynitride<sup>^</sup> or rare earth elements<sup>71</sup> has been found to improve both its fracture toughness and aspect.

As a coating, partially stabilized zirconia seems to provide alumina with an increased mechanical resistance<sup>72</sup>. Coating alumina with other oxides may render the treated attachments bondable in a wider range of conditions. Thus, tin oxide, known to bond well acrylates to both glass ionomer cements and porcelains<sup>74</sup>, allows alumina to give bonds which, as a difference from the ones obtained by silanation, are hydrolytically stable<sup>75</sup>.

Despite the general perception that glasses are too brittle, silicates have been recently claimed to be able to replace both Al or Zr oxides even in the manufacture of direct bonding brackets. Thus, Ormco has patented a protecting outercoating layer<sup>76</sup>, and "A"-Co. an ion-exchange strengthened lithium-aluminum silicate<sup>77</sup>. (It is known that by replacing smaller cations with larger ones, a toughening takes place, due this time to the swelling of the outer layer). **For references, see page 8**

## ANSWERS TO OUR PAST QUIZES

In the June 1994 issue of "Phoenix Without Ashes", we asked our readers in which movie, the famous actor we are showing a picture has expressed a funny opinion about the withdrawal symptom caused by wearing orthodontic appliances.

The movie is "*Mr. Hobbs takes a vacation*", Twentieth Century Fox, 1962, the famous actor *James Stewart*, and his line is: "*Another one (his teenage daughter) is resigning from the human race because she has some chickenwire on her mouth*".

Either the quiz was too difficult, or the picture not good enough, as no winners claimed the prize.

In the September 1994 issue, we launched a contest for the five best explanations of our newsletter name, "Phoenix Without Ashes". We have received many answers, of which we have selected the following:

**Dr. Neil L. Blitz, Warwick, RI:** Your company renews orthodontic brackets by slow chemical dissolution of the adhesive, as opposed to the heat used by your competitors.

**Dr. Ralph Smith, Beaver Creek, OH:** The renewal of a bracket is done without heat & without destroying it in the process.



**Dr. Joseph M. Sim, Edwardsville, IL:** The "rejuvenation" occurs without the heat that would change the internal structure of the metal alloy that makes up the bracket.

**Dr. Larry W. White, Hobbs, NM:** The restoration is achieved without heat, known to lead to ashes and metallic compromise.

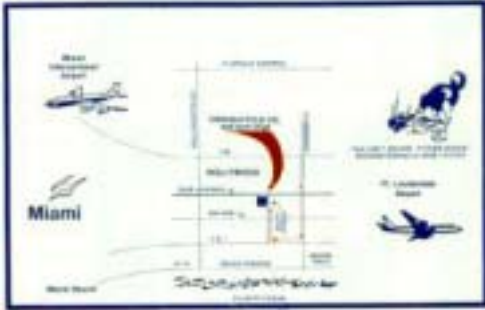
**Dr. Ronald W. Kohl, Jamestown, NY:** Rebirth without destruction.

The above winners are asked to send us a letter specifying their preferred reward: five cases of reconditioned brackets, any brand, or a check for \$100.

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