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RESEARCH ARTICLE

SMART MATERIALS IN DENTISTRY

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ABSTRACT

Change is inevitable. With the advent of time, several changes have occurred in the field of dentistry as well. The era of smart materials has changed the face of dentistry drastically. Smart materials are materials that have properties which may be altered in a controlled fashion by various stimuli. Several such materials are discussed in this paper. Understanding their use and application in specific situations seems to pose a challenge for many dentists. With further research and development, there still is scope to go one step further and develop a class of multi-functional materials which will possess the capability to select and execute specific functions intelligently in order to respond to changes in the local environment. The benefit for the patient and the quality of dental therapy will undergo a significant improvement if such materials are developed and introduced.

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INTRODUCTION

The world has recently undergone two material ages, the plastic age and the composite age. Now a new era has developed, the Smart Materials era. In the last ten decades, concept has been driving towards composite materials and recently, the next evolutionary step is being contemplated with the concept of smart materials. Smart materials are materials that have properties which may be altered in a controlled fashion by stimuli such as stress, temperature, moisture, pH, electric or magnetic fields. (John *et al*., 2009) The property altered can be a change in color, a change in refractive index, a change in the distribution of stresses and strains or a volume change. Key feature of smart materials is their inclusion in structures of materials. These are known as smart structures. Smart structures are simply structures with atleast one smart material incorporated within its structure and that from the effect of smart materials cause an action. Smart structures are being designed to make our life more productive and easy. (James A Harvey, 2009)

Nature of Smart Materials

a) Piezoelectric material: Piezoelectric materials are very common example of such materials where they produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample. Suitably designed structures made from these materials can therefore be made that bend, expand or contract when a voltage is applied. They can also be used in optical-tracking devices, magnetic heads, dot-matrix printers, computer keyboards, high-frequency stereo speakers, accelerometers, micro-phones, pressure sensors, transducers and igniters for gas grills.[3] In dentistry, this phenomenon is most commonly used in piezo scalers. For example, **KaVo PIEZO soft.**

b) Electrostrictive materials: This material has the same properties as piezoelectric material, but the mechanical change is proportional to the square of the electric field. This characteristic will always produce displacements in the same direction. (Susmita Kamila, 2013)

c) Magnetostrictive materials: Magneto restrictive materials similar to piezoelectric, respond to only magnetic fields rather than electric. They are typically used in low-frequency, high-power sonar transducers, motors and hydraulic actuators. (Susmita Kamila, 2013) magnetostrictive materials consists of ferromagnets. One example used in dentistry is magnetostictive ultrasonic scaler. For example, Dentsply Cavitron™.

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d) Elastosrtictive materials: These smart materials exhibit high hysteresis between stress and strain. (James A Harvey, 2009) When stress or strain is removed from an elastostrictive material, the atoms in a part of material does not revert back to its original configuration.

e) Electrorheological materials: These materials can change their rheological properties instantly through the application of either an electric or magnetic field. The rheological properties of these fluids which are usually uniform dispersions or suspensions of particles within a fluid are changed with the application of an electric field. (James A Harvey, 2009)

f) Magnetorheological materials: These materials are magnetic equivalent of electrorheological materials. These fluids consist of either ferromagnetic or ferromagnetic particles that are either dispersed or suspended within; and an applied stimulus is magnetic field. (James A Harvey, 2009)

g) Thermoresponsive material: Amorphous and semi crystalline thermoplastic materials are unique due to presence of a glass transition temperature. At their glass transition temperature, the specific volume of polymer and its rate of change changes. This transition affects multitude of physical properties. An example of such materials is fabric based on polyethylene glycol modified cotton which on application of temperature and moisture act as pressure bandage. (James A Harvey, 2009)

h) pH sensitive materials: pH-sensitive materials are the materials that change their colour as a result of changing acidity. photochromic materials are those which change colour in response to light. This can be observed in light sensitive spectacles that darken when exposed to bright sunlight. There are also certain paints such as thermochromic and photochromic paints, which change colour on heating and on exposure to light respectively.

I) Light sensitive materials: There are several material families that exhibit different types of behavior to light stimulus. Electrochromism is a change in color as a function of an electric field. Other types of behavior for light sensitive materials are thermochromism, photostrictism, shape changes, colour changes with light caused by electronic configuration due to light. (Susmita Kamila, 2013)

J) Smart polymer: Smart polymers or stimuli-responsive polymers are high-performance polymers that change according to the environment they are in. They are used for the production of hydrogels, biodegradable packaging, and to a great extent in biomedical engineering. In medical and biotechnology, smart polymers usually pertain to aqueous polymer solutions, interfaces and hydrogels. These are polymeric systems that are capable of responding strongly to slight changes in the external medium. It responds by change in its volume. (James A Harvey, 2009)

k) Smart gels: The concept of smart gels is a combination of the simple concept of solvent swollen polymer networks in conjunction with the materials being able to respond to other types of stimuli. Some gels can expand to hundreds of times their original volume or could collapse to expel upto 90% of their fluid content with a stimulus of temperature. This behavior is used in gel based actuators, artificial muscles for robotic devices, controlled release system for drugs, etc. (James A Harvey, 2009)

l) Smart catalysts: Smart catalyst functions opposite to traditional catalyst that is as the temperature increases, it becomes less soluble, precipitating out of reaction solution thus becoming inactive. As the reaction solution cools down, the smart catalyst redissolves and thus becomes active again. (James A Harvey, 2009) One such smart catalyst is rhodium based with a poly ethylene oxide backbone.

m) Shape memory alloys: Shape Memory Alloys (SMAs) are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature. The SMAs have two stable phases - the high-temperature phase, called austenite and the low-temperature phase, called martensite. Shape memories as well as superelasticity are the results of a thermo-elastic martensitic transformation. Above the transformation temperature, Nitinol, a Nickel-Titanium alloy with approximately 50 at. % Titanium is austenitic. The crystalline structure of the austenite is a cubic B2 or caesium chloride structure. Cooling below the transformation temperature transforms the B2 structure into a twinned monoclinic structure, called martensite. No macroscopic shape change occurs with this transformation. However, the twinned martensite can be easily deformed up to approximately 8% strain by unconventional de-twinning mechanism. This deformation can be recovered by heating the material to temperatures above the transformation temperature, completing the shape memory cycle. (Rogers, 1988)

n) Unusual behavior of materials: As one researches in the field of smart materials and structures, one realizes that there are many smart materials or that there are many material behaviours that are reversible within their lifetime. The ability to develop useful products from smart materials is left upon one's imagination. For example, water is a very unique material. It expands upon freezing. And as we know, the forces generated by this expansion causes sidewalk and highways to crack. Now, what if you surround water pipes with heating system that consists of a heater and water enclosed in piezoelectric polymer or elastomer container that is in a fixed space. As the temperature drops down to freezing point of water, it expands and generates force against the piezoelectric container which in turn generates electricity, thus powering the heater keeping the pipes from freezing. (James A Harvey, 2009)

Structure of smart materials

The definition of smart structure was topic of controversy from late 1970s to 1980s.at US Army Research office, a special workshop was organized in 1988 where *sensors, actuators, control mechanism, timely response* was recognized as four qualifying features of any smart structure. In this workshop, the following definition of smart structure was adopted. "a system or material which has built in or intrinsic sensors, actuators and control mechanism whereby it is capable of sensing a stimulus, responding to it in a predetermined manner and extent, in a short time and reverting to its original state as soon as stimulus is removed".[5] Both the actuator and sensor function with their appropriate feedback and must be properly integrated. It should be noted that if the response is too slow or too fast, the system could lose its application or could be dangerous. The aim of research in the field of smart structures is to enable a structure to mimic living organisms which possess a system of distributed sensory nerves running all over the body enabling brain to monitor the condition of various body parts. So a smart structure is a system that incorporates particular functions of sensing and actuation to perform smart actions in an ingenious way. The basic five components of a smart structure are summarized as follows:

Data Acquisition (tactile sensing): the aim of this component is to collect the required raw data needed for an appropriate sensing and monitoring of the structure.

Data Transmission (sensory nerves): the purpose of this part is to forward the raw data to the local and/or central command and control units.

Command and Control Unit (brain): the role of this unit is to manage and control the whole system by analyzing the data, reaching the appropriate conclusion and determining the actions required.

Data Instructions (motor nerves): the function of this part is to transmit the decisions and the associated instructions back to the members of the structure.

Action Devices (muscles): the purpose of this part is to take action by triggering the controlling devices/units.

Biomedical application of smart material

Smart pressure bandages:

Polyethylene glycol bonded to various fibrous materials such as cotton and polyester possess the intelligent properties of thermal adaptability and reversible shrinkage. Reversible shrinkage involves imparting a "dimensional memory" to the material such that when material is exposed to a liquid such as water, it shrinks in area. Such materials could be used for pressure bandages that contract when exposed to blood, thereby putting pressure on a wound. One more type of smart bandages are being developed at the University of Rochester which change color not only to warn patients and doctors that there is an infection, but also to specify which bacteria are present. The smart bandage is a thin sensor made of crystalline silicon and layers of porous silicon. The porous silicon is treated with a liquid that contains probe molecules engineered to bind to fat molecules found on the surface of specific bacteria. When the bandage is placed over an infected area, bacteria from the wound move into the porous silicon and attach themselves to the probe molecules, altering the optical properties of the silicon. Doctors illuminate the bandage with light from a handheld semiconductor laser device and the bandage luminance in a color that indicates the kind of bacteria that are present, for example red for E. coli or yellow for strep. With the immediate diagnosis of the culprit germs, doctors won't have to wait for the results of laboratory cultures. Researchers at the University of California, San Diego, are working on similar sensors. Refinements to the technology should help smart bandages make their way into hospitals within a year or two as sensors embedded in the mesh of standard dressings. (http://www.technologyreview.com/article/401917/smart-bandage)

Smart sutures

Surgical sutures have not remained threads anymore. Researchers have now coated them with sensors that could monitor wounds and speed up healing. The electronic sutures, which contain ultrathin silicon sensors integrated on polymer or silk strips, can be threaded through needles, and in animal tests researchers were able to lace them through skin, pull them tight, and knot them without degrading the devices. The sutures can precisely measure temperature—elevated temperatures indicate infection—and deliver heat to a wound site, which is known to aid healing. According to John Rogers, professor of materials science and engineering at the University of Illinois at Urbana-Champaign and inventor of the smart sutures imagine that they could also be laden with devices that provide electrical stimulation to heal wounds. The smart sutures rely on silicon-based devices that flex and stretch. The researchers first use chemicals to slice off an ultrathin film of silicon from a silicon wafer. With a rubber stamp, they lift off and transfer the nano membranes to polymer or silk strips. Then they deposit metal electrodes and wires on top and encapsulate the entire device in an epoxy coating. (Dae-Hyeong Kim *et al*., 2012) They have built two types of temperature sensors on the sutures. One is a silicon diode that shifts its current output with temperature; the other, a platinum nano membrane resistor, changes its resistance with temperature. The micro-heaters, meanwhile, are simply gold filaments that heat up when current pass through them.

Drug delivery

Hydrogels are three-dimensional, cross-linked networks of water-soluble polymers. Hydrogels can be made from virtually any water-soluble polymer, encompassing a wide range of chemical compositions and bulk physical properties. Furthermore, hydrogels can be formulated in a variety of physical forms, including slabs, microparticles, nanoparticles, coatings, and films. As a result, hydrogels are commonly used in clinical practice and experimental medicine for a wide range of applications, including tissue engineering and regenerative medicine, diagnostics, cellular immobilization, separation of biomolecules or cells, and barrier materials to regulate biological adhesions. The unique physical properties of hydrogels have sparked particular interest in their use in drug delivery applications. Their highly porous structure can easily be tuned by controlling the density of cross-links in the gel matrix and the affinity of the hydrogels for the aqueous environment in which they are swollen. Their porosity also permits loading of drugs into the gel matrix and subsequent drug release at a rate dependent on the diffusion coefficient of the small molecule or macromolecule through the gel network. Indeed, the benefits of hydrogels for drug delivery may be largely pharmacokinetic – specifically that a depot formulation is created from which drugs slowly elute, maintaining a high local concentration of drug in the surrounding tissues over an extended period, although they can also be used for systemic delivery. (McLean *et al*., 1994) Some of the hydrogels used for drug delivery are Poly (lactic–glycolic acid), hydroxyethylcellulose, starch, nano composite hydrogels. (Arti Vashist and Sharif Ahmad, 2013)

Gene carriers

Polyelectrolytes have high potential as biomaterials in delivering oppositely charged molecules. One of the most promising applications of pH-sensitive polymers is as non-viral gene carriers. Naked DNA is very difficult to incorporate into the cells because it is negatively charged and it has a very large size at physiological conditions. Liposomes and polycations are the two major classes of chemical (non-viral) gene delivery methods to condense DNA in charge balanced nanoparticles that can be carried into cell compartments. Anionic polyelectrolytes have been used in the development of new intracellular delivery systems by membrane destabilizing mechanisms. These polymers can be tailored to interact actively with phospholipid membranes upon external stimulation, such as acidification of the surrounding medium. This strategy has been exploited to improve the cytoplasmic delivery of biomolecules, (DNA, proteins) that enter cells by endocytosis and end up in acidic organelles. Hoffman's group has dedicated great efforts to obtain new delivery systems to introduce efficiently biomolecules to intracellular targets. They mimicked the molecular machinery of some viruses and pathogens that are able to sense the lowered pH gradient of the endosomal compartment and become activated to destabilize the endosomal membrane. This mechanism enhances protein or DNA transport to the cytoplasm from intracellular compartments such as endosome. According to them the use of poly(2-propylacrylic acid) enhances protein and DNA intracellular delivery. (Aguilar *et al*., 2007)

Countering radioactive rays

Composite containment structures can be used to counter radioactive or chemical waste materials. Fibres with chemically sensitive coatings or radiation sensitive coatings may be provided which are adapted to release scavenger compounds when radiation or chemical waste is detected.

Smart materials in dentistry

1) Shape memory alloys

Nitinol is the names given to a family of inter metallic alloys of nickel and titanium which have been found to have unique properties of shape memory and super-elasticity. (Thompson, 2000) Nitinol includes orthodontic wires and Ni-Ti files are included.

a) Orthodontic wires

The strength and resilience of Ni-Ti wires meant there was a reduction in the number of arch wire changes necessary to complete treatment. Rotations of teeth can be accomplished in a shorter time, without increasing patient discomfort. Nitinol wires show better resistance to corrosion so are felt more appropriate for intraoral use than stainless steel. Andreasen & Morrow (1978) observed the unique properties of Nitinol, including its outstanding elasticity (which allows it to be drawn into high-strength wires) and its 'shape memory' (which allows the wire when deformed, to 'remember' its shape and return to its original configuration). The most important benefits of nitinol wire were its construction as a resilient, rectangular wire that allowed simultaneous rotation, leveling, tipping and torquing movements, to be accomplished early in treatment. Limitations to the use of the material were noted, such as the time taken to bend the wires, the necessity of not using sharp-cornered instruments that could lead to breakage and the inability to be soldered or welded to itself. Overall, the authors felt the material represented a significant improvement over conventional arch wire and was a valuable addition to the orthodontist's armamentarium. (Thompson, 2000)

b) Ni-Ti files:

Ni-Ti alloys used in root canal treatment contain approximately 55% (wt) Ni and 45%(wt) Ti, equivalent to 50%(at) Ni and 50%(at) Ti. (Diogo Montalvao *et al*., 2014) The smart behavior of Ni-Ti alloys is because of two salient features called "super elasticity" and "shape memory". This smart property is the result of substance's ability to undergo a phase change–a kind of atomic ballet in which atoms in the solid subtly shift their positions in response to a stimulus like a change in temperature or application of mechanical stress. In endodontics, the root canal treatment causes stress to Ni-Ti files and a stress induced martensite transformation occurs from the austenitic to the martensitic phase within speed of sound. A change in shape occurs together with volume and density changes. Ni-Ti shaft is made of premium nickel-titanium with many times more flexible compared to stainless steel files. It produces smooth and progressive enlargement of root canal. Ni-Ti follows existing canal path and has memory so there is no need to pre-bend the files. Ni-Ti resists spontaneous breakage. Increased angular rotation reduces fracture. Ni-Ti decreases zipping and stripping. (http://www.diadent.com/products/NTfiles.htm) Ni-Ti rotary systems seem to create more centered canal preparations than stainless steel hand files. (Glosson *et al*., 1995; Portenier *et al*., 1998) Differences are more pronounced at a final preparation larger than size #30. (Esposito and Cunningham, 1995) Elasticity of Ni-Ti greatly reduces the degree of anti-curvature filing that can be accomplished with these instrument. (Lars Bergamns *et al*., 2001)

The size #15 nitinol hand files have been shown to have two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture (wider range of elastic deformation), when compared with size #15 stainless steel files manufactured by the same process. (Walia *et al*., 1988; Tepel *et al*., 1997) Ni-Ti files can be used in two ways, as hand files and as rotary files. Rotary files are most preferred nowadays. The past few years have seen a dramatic increase in the number of manufacturers producing NiTi rotary files. The most popular systems are marketed by Tulsa Dental and Sybron Endo (formally Analytic Technologies). Tulsa markets both the ProSystem GT and ProTaper lines of rotary instruments, where Sybron Endo markets K3 (the successor of the Quantec line of files. (Lieutenant Brent *et al*., 2003)

2) Smart composites

Composite resins have been introduced into the field of conservative dentistry to minimize the drawbacks of the acrylic resins that replaced silicate cements (the only aesthetic materials previously available) in the 1940s. Dental composite resins are types of synthetic resins which are used in dentistry as restorative materials or adhesives. Synthetic resins evolved as restorative materials since they were insoluble, aesthetic, and insensitive to dehydration and were inexpensive. Composites are used in almost all types and sizes of restorations. Such restorations are accomplished with minimal loss of tooth structure. As the researches about composite increased, there came composite which could be called as “smart”. They are ACP releasing composite and self healing composites.

a) ACP releasing composite

ACP based materials have been developed for a number of applications like bases/liners, orthodontic adhesives, endodontic sealers, and as pit and fissure sealants. ACP has been evaluated as a filler phase in bioactive polymeric composites. The ACP has the properties of both a preventive and restorative material that justify its use in dental cements, sealants, composites. (Schumacher *et al*., 2007; Skrtic *et al*., 2003) Skrtic has developed unique biologically active restorative materials containing ACP as filler encapsulated in a polymer binder, which may stimulate the repair of tooth structure because of releasing significant amounts of calcium and phosphate ions in a sustained manner. In addition to excellent biocompatibility, the ACP containing composites release calcium and phosphate ions into saliva milieus, especially in the oral environment caused by bacterial plaque or acidic foods. Then these ions can be deposited into tooth structures as apatite mineral, which is similar to the hydroxyapatite (HAP) found naturally in teeth and bone. ACP at neutral or high pH remains as ACP. When low pH values (at or below 5.8) occur during a carious attack, ACP converts into HAP and precipitates, thus replacing the HAP lost to the acid. So, when the pH level in the mouth drops below 5.8, these ions merge within seconds to form a gel. In less than 2 minutes, the gel becomes amorphous crystals, resulting in calcium and phosphate ions. ACP-filled composite resins have been shown to recover 71% of the lost mineral content of decalcified teeth. (Skrtic *et al*., 1996) This response of ACP containing composites to pH can be described as smart.

b) Self healing composites

Materials usually have a limited lifetime and degrade due to different physical, chemical, and/or biological stimuli. These may include external static (creep) or dynamic (fatigue) forces, internal stress states, corrosion, dissolution, erosion, or biodegradation. This gradually leads to a deterioration of the materials structure and finally failure of the material. Nature has inspired scientists and researchers to develop materials which can repair by themselves. There are many natural “materials” which are themselves self-healing composite materials. An example for this is natural bone which is permanently remodeled and which can self-repair (heal) even after a major fracture has occurred. One of the first self-repairing or self-healing synthetic materials reported interestingly shows some similarities to resin-based dental materials, since it is resin-based. This was an epoxy system which contained resin filled microcapsules. If a crack occurs in the epoxy composite material, some of the microcapsules are destroyed near the crack and release the resin. The resin subsequently fills the crack and reacts with a Grubbs catalyst dispersed in the epoxy composite, resulting in a polymerization of the resin and a repair of the crack. Once healed, the polymer recovers as much as 90% of its original fracture toughness. (http://otm.illinois.edu/technologies/polymeric-self-healing-composites-longer-lasting-p)

Similar systems were demonstrated to have a significantly longer duty cycle under mechanical stress in situ compared to similar systems with the self-repair. It can be expected that dental composites using this technology would have a significantly longer duty cycle and enhanced clinical performance. Problems may arise from the potential toxicity of the resins in the microcapsules and from the catalyst, which needs to be present in the composite. The amounts of these agents necessary to repair microcracks in the dental composite, however, seem to be rather small, and may well be below the toxicity threshold. The self-repairing mechanism based on microcapsules may be more promising and composites repaired in that way may perform better than those repaired with macroscopic repair approaches, some of have been shown not to lead to satisfactory mechanical properties of the repaired composite with an aesthetically pleasing result.

3) Smart ceramics:

In dentistry, there has been continuous research and development to find materials suitable for dental prosthesis that are aesthetically acceptable, of sufficient strength and which are perfectly tolerated by the human body. For many years ceramic materials combined with metals have been used in dental restorations, ceramic to achieve the desired aesthetics, metal for strength. (http://www.silomdental.com/cercon_smart_ceramic1.html) In case of incisor teeth, it is usual to see that although the crown is esthetic, the replacement still does not give impression of a natural tooth. The main reason is that the crown is supported by a metal substructure which means that it is less translucent than natural teeth. The advent of superior and innovative technology has made the process of restoring teeth to their original and natural form easy and predictable. (Little and Crocker, 2003) The problem can be solved by using metal free ceramic crown. A metal free ceramic crown, cercon remains un-noticeable even for an expert eye. The cercon has been developed by Swiss researchers. A notable feature of Cercon zirconia restorations is the ultra-thin monolithic material, which contributes maximum strength capabilities. The restorations are milled from a monolithic block of solid yttria-stabilized zirconia. The combination of high flexural strength, high fracture toughness, and partially stabilized zirconia increases the lifespan of restorations. Furthermore, chipping which is a common problem with layered zirconia restorations has been eliminated due to scientific technology contributing to the strength and longevity of the material. The level of durability for Cercon zirconia as compared to similar materials after adjusting and repolishing also demonstrates the material’s safety for opposing antagonist teeth. (DENTSPLY International Inc. Cercon ht Full Contour Zirconia, 2011) Other advantages of Cercon zirconia are its simple clinical protocol for conservative tooth reductions, requiring the removal of as little as 0.5 mm to 1 mm of the patient's natural tooth structure. Additionally, the effortless chair side preparation saves valuable time. Moreover, conventional or adhesive techniques can be used for seating restorations that will fulfill case-specific requirements. (http://www.dentalaegis.com/id/2012/12/a-smart-ceramics-system-for-expanded-indications) When preparing cercon, the lab technician uses CAD/CAM technology to design the anatomical features, size and shape of a tooth restoration on a computer. The CAD/CAM computer screen displays a 3 D image of your teeth and gums, allowing your dentist to use a cursor to draw the precise design of the tooth restoration. The CAD/CAM machine fabricates the restoration through milling chamber that crafts the tooth like ceramic material into a precise replica of the drawing. The cercon system provides high stability. The approach is to machine a pre-fabricated ceramic blank made of zirconia ceramics with a nano-crystalline porous structure in the pre-sintered state. After machining the soft ceramic component in the pre-sintered state, it is sintered and thereby shrinks to its final dimensions. This shrinkage is designed to take place very homogeneously in all spatial directions. The new machine fabricates the complex shape of dentures from the ceramic blanks with high accuracy in an easy, fast, and fully automated way. The machined component obtains its high hardness, high strength, and toughness after the machining step during the final sintering. The veneering of the high strength ceramic framework then adds the required aesthetic and wear characteristics. It is an anti allergic, translucent, biocompatible and has low thermal conductivity.

4) GIC as a Smart material:

Wide temperature fluctuations may occur in the oral cavity due to the intake of hot or cold food and fluids. Hence, the restorative materials placed in this environment may show thermal expansion or contraction in response to thermal stimuli. The coefficient of thermal expansion (CTE) is normally used to describe the dimensional changes of a substance in response to thermal change. When dealing with thermally induced volumetric changes, comparison of CTE values of the restorative material and the tooth substance is more important than the CTE value of the material itself. The mismatch of thermal expansion and contraction between a restoration and the tooth structure may cause stresses to develop at the interface and this may have unfavorable effects on the margins and finally lead to microleakage. For glass-ionomers, little or no change in dimension was observed when heating and cooling between 20 ^{0}C and 50 ^{0}C in wet conditions. In dry conditions, the materials showed a marked contraction when heated above 50 ^{0}C. The explanation for this behavior is that the expected expansion on heating is compensated by fluid flow to the surface of the material to cause a balancing of the dimensional changes. On cooling, the process is reversed. In dry conditions, the rapid loss of water on heating results in the observed contraction. This behavior is akin to that of human dentine where very little dimensional change is observed on heating in wet conditions and a marked contraction is noted in dry conditions. Both results can be explained by flow of fluids in the dentinal tubules. Hence, the glass-ionomer materials can be said to be mimicking the behavior of human dentine through a type of smart behavior. Moreover, glass ionomer cement (GICs) has the ability to reuptake and release fluorides from commonly used sources like fluoridated dentifrices. This property has the potential to provide a continuous low concentration of fluoride in the saliva aiding in caries prevention. (Rao and Sudha, 2011) There is evidence that the fluoride released from salt phases can be replaced when the material is bathed in a high concentration of fluoride as may occur in a toothpaste or mouth rinse. (Yan *et al*., 2007) The smart behavior of glass ionomers and related materials is also closely linked to their water content and the way in which this can react to changes in the environment. Clearly, there are different ways in which water can be retained in and transported through the cement structure. One important feature which may provide a location for the formation of reservoirs within the material is porosity. The number and size of pores within a cement can be controlled by the method of mixing. In the low viscosity material, hand mixing reduces the porosity significantly compared to mechanical mixing; either by shaking or rotation. For the viscous material levels of porosity are low and not significantly affected by mixing. These differences in porosity are reflected in differences in water absorption. Hence, this aspect of the smart behaviour of dental cements can be controlled by the operator. (John *et al*., 2009)

5) Compomers:

Polyacid modified composite resins known as compomers, are a group of aesthetic materials for restoration of teeth damaged by dental caries. The trivial name was devised from the names of two parent materials, that are composite and ionomer. It is used in class I, class ii, class v restorations, as a fissure sealants and as orthodontic band cement. It is usually light-initiated, and the inititor is camphorquinone with amine accelerator and as such is sensitive to blue light at 470 nm. (Meyer *et al*., 1998) A key feature of compomers is that they contain no water and the majority of components are the same as for composite resins. Typically these are bulky macro-monomers, such as bisglycidyl ether dimethacrylate (bisGMA) or its derivatives and/or urethane dimethacrylate, which are blended with viscosity-reducing diluents, such as triethylene glycol dimethacrylate (TEGDMA). These polymer systems are filled with non-reactive inorganic powders, such as quartz or a silicate glass, for example SrAlFSiO4. (Eliades *et al*., 1998) Compomers contain additional monomers that differ from those in conventional composites, which contain acidic functional groups. The most widely used monomer of this type is so-called TCB, which is a di-ester of 2-hydroxyethyl methacrylate with butane tetracarboxylic acid. This acid-functional monomer is very much a minor component and compomers also contain some reactive glass powder of the type used in glass-ionomer cements. (McLean *et al*., 1994) Moreover, a distinctive feature of compomer is that following initial polymerization, they take up small amount of water. This triggers an acid base reaction between reactive glass filler and the acid groups of functional monomer. Among other features, this process causes fluoride to be released from the glass filler to the matrix from where it can readily be released into mouth. Polymerization is associated with contraction and the development of stresses and it may be that the sorption of water plays some part in reducing these stresses. Compomers are designed to absorb water and are able to up of the order of 2-3.5% by mass of water on soaking. This water uptake has shown to be accompanied by neutralization of carboxylic acid groups. Compomers are designed to release fluoride in clinically beneficial amounts. Fluoride is present in the reactive glass filler and becomes available for release following reaction of this glass with the acid functional groups, triggered by moisture uptake. In addition commercial compomers contain fluoride compounds such as strontium fluoride or ytterbium fluoride which are capable of releasing free fluoride ion under clinical conditions and augment the relatively low level of release that occurs from the polysalt species that develops. Fluoride release occurs to enhanced extents in acidic conditions and in lactate buffer has shown to be diffusion based. It is stated that fluoride releasing ability of compomers can be regenerated by using a topical fluoride agent.hih release compomers appear to have greater recharging capacity than low release ones. Compomers have been found to change the pH of lactic acid in the direction of neutral. This property was seemed to be repeatable when samples were exposed to fresh lactic acid at weekly interval over a period of 6 weeks. This behavior of buffering has been observed for GIC too. It is therefore the property conferred by acid base components of the compomer.

6) Smart fibers for laser dentistry- Hollow core photonic crystals:

According to Strass *et al*. 2002, transmission of high energy laser pulses capable of ablating dental tissues is a crucial issue in laser dentistry. Short laser pulses have shown to be more advantageous over longer pulses of conventional laser delivery system. Short laser pulses allow undesirable cracks and shockwave formation to be avoided and thermal loads to be minimized thus improving the quality of crater rims. In view of these growing short laser pulses application, the non-linear optical processes enhancement is observed which give rise to undesirable effects in radiation transmission. Optical non linearities along with laser breakdown often restrict the use of standard optical fibers to insufficiently ablate dental tissues. Also the large core area silica fibers which are standard optical fibers used nowadays, intended to guide high-power laser pulses often have durability problems. Approaches to high energy laser beam delivery allowing these limitations to be overcome would thus promote laser dentistry technologies to a qualitatively new level. Hollow core fibers allow the fluence of guided laser pulses to be substantially increased relative to standard silica-core optical fibres since the gases filling the core of hollow fibres have much higher laser breakdown threshold and much weaker optical non-linearities as compared to fused silica. Experiment carried out by S O Konrov *et al*. 2003, sequences of picoseconds pulses of 1.06 µ Nd: YAG laser radiation with a total energy of about 2mJ can be transmitted through hollow core photonic crystal fibres with a core diameter of approximately 14 µm. Such energy of laser pulses coupled into a hollow core of photonic crystal fibre with a core diameter of 14 µm corresponds to fluence of 180 J/cm, which is more than an order of magnitude higher than the typical breakdown threshold of fused silica. Experimental studies demonstrate that the excitation of higher order waveguide modes and related beam distortion effects can be avoided in hollow core PCFs with an appropriate choice of parameters of fibres and laser pulses. Being focused on tooth surface, these PCF delivered laser pulses lead to an ablation of enamel tissue. Hollow core photonic crystal fibres are shown to support the single fundamental mode regime for 1.06 µm laser radiations, serving as a spatial filter allowing the laser beam quality to be substantially improved. (Stanislav konrov *et al*., 2004)

7) Smart seal Obturation System:

Obturation of root canals should prevent reinfection of the canal space and ultimately prevent periradicular disease. This objective may be achieved by three-dimensional filling of the instrumented canal, accessory canals, and dead spaces. While different canal filling techniques are currently available to achieve this goal, there is ongoing interest in developing simplified obturating materials/techniques for filling irregular shaped canals and to minimize voids created during obturation procedures, which may act as nidi for growth of residual biofilms. The C Point system or pro-point (EndoTechnologies, LLC, Shrewsbury, MA, USA) is a point-and-paste root canal filling technique that consists of premade, hydrophilic endodontic points and an accompanying sealer. The deformable endodontic point (C Point) is available in different tip sizes and tapers and is designed to expand laterally without expanding axially, by absorbing residual water from the instrumented canal space and that from naturally-occurring intraradicular moisture. The inner core of C Point is a mix of two proprietary nylon polymers: Trogamid T and Trogamid CX. The polymer coating is a cross-linked copolymer of acrylonitrile and vinylpyrroli done, which has been polymerised and cross-linked using allyl methacrylate and a thermal initiator. The lateral expansion of C Point is claimed to occur non uniformly, with the expandability depending on the extent to which the hydrophilic polymer is prestressed (i.e., contact with a canal wall will reduce the rate or extent of polymer expansion). This no isotropic lateral expansion is said to enhance the sealing ability of the root canal filling, thereby reducing the possibility of reinfection and potentiating the long-term success of root canal treatment. As claimed by the manufacturer, although C Point is capable of achieving a relative good fit of an irregular canal space, gaps may still remain between the walls of the canal and the expanded point. An accompanying sealer must be used to seal those areas. Smart paste bio is a resin-based sealant designed to swell through the addition of ground polymer. The manufacturer claims that the addition of bioceramics gives the sealer exceptional dimensional stability and makes it non-resorbable inside the root canal. Smartpaste bio produces calcium hydroxide and hydroxyapatite as by-products of the setting reaction, rendering the material both antibacterial while setting and very biocompatible once set. Also, it has a delayed setting time (4–10 hr) and is hydrophilic in nature, allowing the propoint to hydrate and swell to fill any voids. (Lumbini Pathvida *et al*., 2013)

8) Smart Coatings for Dental Implants:

Researchers at North Carolina State University have developed a “smart coating” that helps surgical implants bond more closely with bone and ward off infection. This has opened the doors to safer hip, knee, and dental implants. When patients have hip, knee, or dental replacement surgery, they run the risk of having their bodies reject the implant. But the smart coating developed at NC State mitigates that risk by fostering bone growth into the implant. The coating creates a crystalline layer next to the implant and a mostly amorphous outer layer that touches the surrounding bone. The amorphous layer dissolves over time, releasing calcium and phosphate, which encourages bone growth. The bone grows into the coating as the amorphous layer dissolves, resulting in improved bonding, or osseointegration. This bonding also makes the implant more functional, because the bonding helps ensure that the bone and the implant do a better job of sharing the load. The researchers have also incorporated silver nano particles throughout the coating to ward off infections. Currently, implant patients are subjected to an intense regimen of antibiotics to prevent infection immediately following surgery. However, the site of the implant will always remain vulnerable to infection. But by incorporating silver into the coating, the silver particles will act as antimicrobial agents as the amorphous layer dissolves. This not only will limit the amount of antibiotics patients will need following surgery, but also will provide protection from infection at the implant site for the life of the implant. Moreover, the silver is released more quickly right after surgery, when there is more risk of infection, due to the faster dissolution of the amorphous layer of the coating. Silver release will slow down while the patient is healing. That is another reason why the authors call it smart coating.

9) Smart prep burs:

One of the goals of conservative dentistry is to develop a method to remove caries infected dentin while preserving caries affected dentin. The smart prep bur appears to be the instrument to offer straight forward and efficient means of achieving this goal. Smart prep instrument is a medical grade polymer that safely and effectively removes decayed dentin leaving healthy dentin intact. Hardness of instrument is less than that of healthy dentin and enamel but harder than carious dentin. With a Knoop hardness of 50, the system is designed with a reducing cutting capacity when it comes into contact with a surface harder than itself. Tiny polymer flutes in the bur wear away as they contact healthy hard dentin. (http://www.dentistryiq.com/articles/wdj/print/volume-1/issue-4/art-and-sciencetoday/smartpreptrade-todays-new-technology -an-improved-caries-removal-system.html) This self-limiting feature assists in ensuring that diseased dentin will selectively be removed. The polymer instrument is self limiting which do not cut sound dentin unless greater force is applied. Then also it will wear away rather than cut the sound dentin. Smart prep instruments are used in range of sizes equivalent to sizes of round bur no.2, no.4, no.6.they are used with slow speed handpiece (500-800) to complete caries removal. The carious tissue is removed with circular movements from centre to periphery. Its advantage is that it can be used in deep caries removal in anticipation of indirect pulp capping. (http://onlinedentalbook.blogspot.in/2008/09/smart prep-instruments.html) These are polymer burs that cuts only infected dentin. The affected dentin which has the ability to remineralize is left intact. Over cutting of tooth structure that usually occurs with conventional burs can be avoided by the use of these smart preparation bur. Ex: SS White (145 Towbin Avenue, Lakewood, New Jersey, 08701, USA) diamond and carbide preparation kit. (Shanthi *et al*., 2014)

Future and scope of smart materials

Smart material has encompassed all the fields of science and engineering. The future of smart materials is wide open. The use of smart materials in a product and the type of smart structures that one can design is only limited to one's talents, capabilities and ability to think out of box. Great deal of researches for smart materials are going on which is having its effect in the field of dentistry. Newer materials are coming in with unique smart properties. Soon, the word 'smart' would become the integral part of dentistry and dentistry could become "smart dentistry".

Conclusion

There is still lot of confusion in dealing with smart material as what makes the material smart. The field of smart materials and structures is emerging rapidly with technological innovations in medical field, sensors, actuators. There is much room for improvement and further development of materials used in dentistry. But the question arises that can smartness be accommodated without neglecting the other key requirements such as clinical function and longevity. The most sophisticated class of materials in the future would be those which will emulate biological systems. This class of multi-functional materials will possess the capability to select and execute specific functions intelligently in order to respond to changes in the local environment. The benefit for the patient and the quality of dental therapy will undergo a significant improvement if such materials are developed and introduced.

REFERENCES

Aguilar M.R., C. Elvira, A. Gallardo, B. Vázquez, J.S. Román 2007. Smart Polymers and their application as Biomaterials. *Topics in Tissue Engineering*, 3: 2-27.

Arti Vashist, 2013. Sharif Ahmad. Hydrogels: Smart Materials for Drug Delivery. *Orient. J. Chem*., 29(3): 861-870.

Dae-Hyeong Kim, Shuodao Wang, John A. Rogers. 2012. Thin, Flexible Sensors and Actuators as 'Instrumented' Surgical Sutures for Targeted Wound Monitoring and Therapy. Small AUG, 8(21): 3263–3268.

DENTSPLY International Inc. Cercon ht Full Contour Zirconia. York, Pennsylvania: DENTSPLY International Inc, 2011:1-2.

Diogo Montalvao, Francisca Sena Alçada, Francisco Manuel Braz Fernandes. 2014. Structural Characterisation and Mechanical FE Analysis of Conventional and M-Wire Ni-Ti Alloys Used in Endodontic Rotary Instruments. *The Scientific World Journal*, 1-8.

Eliades G, Kakaboura A, Palaghias G. 1998. Acid base reaction and fluoride release profiles in visible light-cured polyacid modified composite resin restorations. *Dent Mater*, 14: 57–63.

Esposito, PT. and Cunningham, CJ. 1995. A comparison of canal preparation with nickel-titanium and stainless steel instruments. *J Endod*., 21: 173-176.

Georges Akhras. Smart materials and smart system for the future. *Canadian Military Journal*, Autumn 2000: 25-32.

Glosson CR, Haller RH, Dove SB, *et al*. 1995. A comparison of root canal preparation using NiTi hand, NiTi engine-driven, and K-Flex endodontic instruments. *J Endod*., 21: 146-151.

http://onlinedentalbook.blogspot.in/2008/09/smartprep-instruments.html.

http://otm.illinois.edu/technologies/polymeric-self-healing-composites-longer-lasting-p.

http://www.dentalaegis.com/id/2012/12/a-smart-ceramics-system-for-expanded-indications.

http://www.dentistryiq.com/articles/wdj/print/volume-1/issue-4/art-and-sciencetoday/smartpreptrade-todays-new-technology-an-improved-caries-removal-system.html.

http://www.diadent.com/products/NTfiles.htm.

http://www.silomdental.com/cercon_smart_ceramic1.html

http://www.technologyreview.com/article/401917/smart-bandage.

James A. 2009. Harvey. Smart materials. Handbook of materials selection, 401-417.

John F, McCABE, Zhuoqn Yan, Omar T, AI NAIMI, Ghaith, Mahmoud and Sarah L. Rolland. 2009. Smart materials in dentistry-future prospects. *Dent Mater J*., 28(1): 37-33.

Lars Bergamns, Johan Van, Martine Wevers, 2001. Mechanical root canal preparation with NiTi rotary instruments: Rationale, performance and safety. Status Report for the American Journal of Dentistry. *American Journal of Dentistry*, October, 14(5): 324-333.

Lieutenant Brent J. Crumpton, Captain Scott McClanahan. 2003. Endodontic rotary nickel-titanium instrument systems Aug., 25(8): 15-16.

Little DA. and Crocker JJ. 2003. Clinical Use of a New Metal Free Restorative Technology. Case Reports. DENTSPLY Asia Update, 1-3.

Lumbini Pathvida, Karthik Krishna Munaga. 2013. Smartseal: New Age Obturation. *Annals of Dental Speciality*, 1(1):13-15.

McLean JW, Nicholson JW, Wilson AD. 1994. Proposed nomenclature for glass-ionomer dental cements and related materials. *Quintessence Int*., 25: 587–9.

Meyer J-M, Cattani-Lorente MA, Dupuis V. 1998. Compomers: between glass-ionomer cements and composites. *Biomaterials*, 19: 529–39.

Portenier I, Lutz F, Barbakow F. 1998. Preparation of the apical part of the root canal by the Lightspeed and step-back techniques. *Int Endod J*., 31: 103-111.

Rao A. and P Sudha, 2011. Fluoride rechargability of a non-resin auto-cured glass ionomer cement from a fluoridated dentifrice: An *in vitro* study, 29(3): 202-204.

Rogers. C. A. 1988. Smart Materials, Structures and Mathematical Issues. September 15-16, 1-230

Schumacher GE, Antonucci JM, O'Donnell JNR, Skrtic D. 2007.The use of amorphous calcium phosphate composites as bioactive basing materials. Their effect on the strength of the composite/adhesive/dentin bond. *J Am Dent Assoc*., 138: 1476–1484.

Shanthi, M., E. V. Soma Sekhar, Swetha Ankireddy. 2014. Smart materials in dentistry: Think smart. Journal of Pediatric Dentistry. Jan-Apr., 2(1): 1-4.

Skrtic D, Antonucci JM, Eanes ED. 2003. Amorphous calcium phosphate-based bioactive polymeric composites for mineralized tissue regeneration. *J Res Natl Inst Stands Technol*., 108: 167–182

Skrtic D, Hailer AW, Takagi S, Antonucci JM, Eanes ED. 1996. Quantitative assessment of the efficacy of amorphous calcium phosphate/methacrylate composites in remineralizing caries-like lesions artificially produced in bovine enamel. *J Dent Res*., 75: 1679–1686

Stanislav konrov, Vladmir Mitrokhin, Michael Scalora, Aleksei Zheltkov. 2004. Hollow core photonic crystal fibres for laser dentistry. *Physics in Medicine and Biology*, 49: 1359-1368.

Susmita Kamila. 2013. Introduction, classification and applications of smart materials: An overview. *American Journal of Applied Sciences*, 10 (8): 876-880.

Tepel J, Schafer E, Hoppe W. 1997. Properties of endodontic hand instruments used in rotary motion. Part 3. Resistance to bending and fracture. *J Endod*., 23: 141-145

Thompson. S. A. 2000. An overview of nickel–titanium alloys used in dentistry. *International Endodontic Journal*, 33: 297–310.

Walia H, Brantley WA, Gernstein H. 1988. An initial investigation of the bending and tortional properties of nitinol root canal files. *J Endod*., 14: 346-35.

Yan, Z., SK Sidhu, GA Mahmoud, TE Carrick, JF McCabe. 2004. Effects of Temperature on the Fluoride Release and Recharging Ability of Glass Ionomers. *Operative Dentistry*, 32(2): 138-143

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