Study on Spray Dried Yttria Stabilized Zirconia Dental Implants

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Abstract. Medical implants are devices, tissues or supports that are positioned in a suitable manner on any defective part of the human body to facilitate its smooth functioning again. Known as ‘prosthetics’, they may be used to offer support to a specific organ or tissues, distribute medication, or observe the body condition. While many of the implants are made from skin, bone or other tissues removed from the body itself, the artificial ones are made from engineering materials which could be any of the compatible metals, plastics, ceramics or even composites. The high end technologically advanced implant material is expected to withstand severe barriers and compatibility issues when in contact with the human body. One such application is dental implants, where, the materials must possess superior mechanical properties, exhibit good hydro-chemical and low thermal degradation characteristics. They are also required to possess characteristics such as low friction, strong wear resistance, good wettability and biocompatibility, when placed in the mouth. The only materials that come close to meeting the needs are ceramics, limited by the associated high fracture rate. Stabilized zirconia (stabilized with yttria, ceria etc.) has provided potential solution. Among the two stabilizers, ceria stabilized zirconia may be a better alternative to yttria stabilized zirconia. Other alternatives are alumina, apatites: but their use are constrained based upon technological and cost considerations. Implant product is a highly demanding technology. Spray drying is a suitable process methodology to obtain free flowing powders with uniform morphology and chemical composition, essential for an implant production. This paper presents (i) results from spray drying 8% Y2O3-stabilized ZrO2 and (ii) a review of published literature pertaining to dental implant materials, the various processing methodologies, with special reference to stabilized zirconia and spray drying.

1. Introduction to Medical Implants: Materials and Processing methods
The use of ceramics in medical applications such as replacements for teeth, knees, hips, tendons, etc., has seen tremendous developments recently. Hydroxyapatite (HA) has a bone bonding capability due to its surface porosity and in addition, extreme closeness to natural bone chemistry. Macro pores usually of about 100μm size help the bone grow into the body structure and grip it. HA with calcium phosphate is a ceramic for physiological application with osteo-conductive (bone grows on surface) property, and hence there is rapid bone formation and strong biological bond to the bone tissues making it suitable for medical implants. To enhance the mechanical property, aesthetics and the biocompatibility of some metal dental implants, plasma sprayed HA coatings are used in conjunction. In a coated component, the strength is derived from the substrate and the performance is derived from the
coating. However, in prosthetics involving coated components there is a weak bond between the coating and substrate. This has led to the development of bio-ceramic composite coatings. Yet another implant system includes the implants in the sintered form where the products are individual entities, e.g. a single whole component, unlike involving 2 parts such as a substrate and overlay coating. Both the functions, of strength and performance in the body environment (e.g. force of chewing and the saliva cum food chemistry inside mouth encountered by dental implants) are carried out by the sintered product. Therefore, the material of the coating or the sintered product plays a crucial role to serve efficiently in the intended purpose.

In addition to the chemical composition of the material, yet another factor that significantly influences the property of the implant is the processing methodology. This is because, positioning the dental implants in dentistry are dependent on many factors such as the anatomic features of the mouth, jaw etc. in general, and more importantly adequate bone height, width, thickness etc. These features may significantly be controlled via processing methodology: some of which being widely researched are additive manufacturing, powder metallurgical methods involving sintering, rapid prototyping, 3D printing, surface treatment by coatings etc. Regardless of the processing methods being employed, the base material composition, grain morphology, uniformity and consistency in properties are of very high significance which are most of the times, attained by the “spray drying” process.

1.1. Spray drying and its principles
A very routinely employed method applied for shaping sintered ceramic implants includes uni-axial presses in an extrusion or die and punch system, into which free flowing agglomerates of nano powder compositions are introduced for compaction and thereafter sintering. The free flowing powder composition obtained via spray drying has several stages and are briefly described below. In this process, slurry of suitable rheology with chosen powder composition and binders are fed into the spray dryer chamber under controlled power, temperature, feed rate, pressure and atomization conditions. Free-flowing powder with pre-set specifications is desirable to guarantee a uniform distribution of the powder composition in almost all the above processes and this exactly is achievable by employing a spray dryer. Any kind of heterogeneity in composition or flowability introduces defective morphology and grain structure in the component leading to inconsistent properties. Spray-drying is well known processing mechanism to obtain specified granulated powders, the physical properties of which are especially amenable to implant processing. Together with uniform chemical composition, the spray dried powder is endowed with key characteristics such as (a) ideal moisture content typically 5 to 20% for development of desired strength and porosity needed for bone tissue growth and chewing strength (2) spherical morphology and low surface roughness (3) desired grain size morphological manifestation and distribution with pre-set agglomerate sizes etc.

In the present work, micron sized free flowing agglomerates of 6 to 8% yttria stabilized zirconia (8YSZ) nano powders were synthesised by employing laboratory spray dryer and characterized for material properties.

2. Experimental Details
Figure 1 shows (a) typical flow chart with steps involved in spray drying method and (b) photograph of the laboratory spray dryer used to perform a simple experiment to synthesize free flowing spray dried agglomerates (20 to 100μm grain size) of 8YSZ nano powders (20 to 100nm individual particle size) in the laboratory. The nano powders used were commercially procured, with certified nano grain sizes (20 to 100nm range) and converted into micron sized free flowing powders. The medium used was distilled water and binder was poly vinyl alcohol (PVA). In addition to studying the spray dried powder morphology and flowability by using a plasma spray feeder system, the powders were characterized for particle size and distribution by employing Scanning Electron Microscope (SEM), associated with Energy dispersive x-ray spectroscopy (EDS) for chemical composition analysis.
3. Results and Discussion
Figure 2 shows the SEM and EDS analysis results from the spray dried 6-8% Y$_2$O$_3$ stabilized ZrO$_2$ powders removed from the chamber shown in Figure 1b.

| Element | Weight % |
|---------|----------|
| O$_{K}$  | 36.58    |
| Y$_{L}$  | 7.63     |
| Zr$_{L}$ | 55.79    |

Figure 2. (a) EDS pattern, (b) chemical composition & (c and d) SEM micrographs of spray dried powders (SPD)
The EDS analysis results (Fig 2) showed the chemical compositions to be comprised of desired yttria and zirconia contents and morphology from SEM micrographs (Figure 2 c and d) were suggestive of free flowing characteristics. The details are beyond the scope of this paper.

The remaining part of this paper involves a brief review of the materials and synthesis methodology employed in the specific applications of dental implants. Spray drying and Yttria stabilized zirconia ceramics and their importance in application as dental implants forms the most significant content in this review section.

4. Role of spray drying as a tool to manufacture free flowing ceramic powders

An economic process of dry pressing method is used to prepare ceramic parts, which requires good powder flow ability. Fine particles tend to accumulate due to strong cohesive forces which prevents packing structure during pressing causing structural defects in the sintered material. Spray dried powders (SDP) consist of agglomerated powder particles, with individual sizes varying between few nano-meters to microns, and can be controlled to desired agglomerate sizes. The agglomerated SDPs facilitate the flow ability of nano-sized grains. “Spray dryers” are used to synthesise clusters of the nano-powders, which are also known as agglomeration. This exercise is carried out, by letting the slurry, which contain the dispersed fine powders in a liquid medium fortified with suitable binders to attain the desired pH values, into the spray dryer chamber at pre-fixed temperature of the hot air medium to allow the agglomeration to take place. The physical characteristics such as uniformity in agglomeration, size-distribution, contour, density and morphology of the SDPs are determined by the spray drying conditions that include the heat content within the chamber coupled with the rate at which the drying medium passes through the spray dryer, percentage of solid in the slurry, rate at which slurry is fed etc. in the spray drying process.

5. Dental implant materials and role of spray drying in their manufacture– a brief review

5.1. Yttria and ceria stabilized zirconia in dentistry:

Camposilvan et.al have discussed the enhanced reliability of yttria stabilised zirconia in dentistry. The application of zirconia as medical implants, for example in dentistry and arthroplasty (surgical replacement) is well known. The usage has increased tremendously due to the higher strength and fracture toughness it provides when compared with the traditionally used alumina implants [1]. When it comes to design, for a specific application, zirconia provides more flexibility as well. It is popularly used in dental applications in dental caps, coning tower (bridge), supporting abutment, dental plates and reinforcements. Interest in zirconia for dentistry is increasing with the significant improvements in CAM/CDA. The advantages of using zirconia is in its translucent flawlessness and straightforward colour alteration for matching the tooth. Zirconia (ZrO₂) is a ceramic with ample mechanical properties for build-up of medical devices. Zirconia stabilized with Y₂O₃ has the simplest properties for these applications. During heating (sintering temperature) and cooling to room temperature, zirconia undergoes a reversible phase change, which can be eliminated with the addition of a touch of yttria, and therefore the resulting material has improved mechanical, electrical and thermal properties. Thus the monoclinic ZrO₂ phase has transformed into a tetragonal phase and it acts as a stabilizing agent.

3 mole % Y₂O₃-stabilized ZrO₂(3YSZ) with tetragonal ZrO₂ crystalline phase structure poly-crystals, is an osteo-conducting ceramic, with dental compatibility, and with enhanced mechanical characteristics with colour similarity. Pre-determined quantities of dopant, i.e. the stabilizer (Y₂O₃ in this case) was added to the monoclinic phase in order to retain the stable state of tetragonal zirconia at room temperature (tetragonal zirconia is a high temperature metastable phase). The stable tetragonal zirconia state can withstand high amounts of stresses. Stabilization of the high temperature t-ZrO₂ phase at room temperature is the key parameter. The amount of dopant added must be sufficient to circumvent the destabilization at sintering temperatures during cooling as well. With 3 mole % of yttria the bending strength of >1000MPa and fracture toughness approximately 5 MPa√m was achieved. It is however, important to note that even minor off-set in synthesis conditions may contribute to the formation of a defective product. The degradation (failure) was attributed to low
temperature degradation (LTD) which was observed under hydrothermal conditions, such as those encountered when used as an implant in the human body. This limitation negatively affected the production of 3Y-TZP implants. The formation of spontaneous and progressive monoclinic zirconia phases under humid and moderate temperature and moisture conditions is known as LTD. As already pointed out, m-zirconia is not a favorable phase for any application of zirconia where mechanical properties are involved (only stable tetragonal zirconia phase is useful). Thus it is essential to retain the tetragonal zirconia phase within the human body (mouth specifically for dental applications). It only occurs on a superficial layer of few mm in fully dense 3Y-TZP whereas in the in-effectively sintered material, large numbers of pores form in the microstructure that lead to breakage of the implant. Yttria, although provides very good stabilization and mechanical properties (strength and toughness) to zirconia, is not the best material for dental implant application. Influence of LTD on fracture strength of 3YSZ implants used in dental application depends upon the aging time under monotonic and cyclic loads (biting and chewing hard food in presence of saliva). The key point to stabilize tetragonal phase zirconia at ambient temperature is controlling presence of vacancies in ZrO\(_2\) lattice generated by Y\(_2\)O\(_3\) which act as receptors for infiltration of moisture with the saliva chemistry during hydrothermal aging that occurs within the mouth. This destabilizes the tetragonal zirconia structure to the undesirable monoclinic zirconia structure. This deficiency can be overcome by using Cerium oxide (CeO\(_2\)) as a stabilizer. Ceria stabilized zirconia (Ce-SZ) resists this type of moisture related aging. Ce-SZ(Te-TZP) and 3YSZ have similar driving forces for transformation but different LTD kinetics. In Ce-TZP there is a lack of extrinsic vacancies, so the first step to degradation is blocked and hence aging is retarded making it more aging resistant. However, doping of Ce with zirconia increases grain size reduces sintering capacity and leaves residual porosity. Though high hydrothermal resistance and immunity to LTD is developed the fracture toughness, hardness and strength is lowered. The process implemented was a liquid infiltration process where alumina was added to the chosen composition by saturating green or partially heat treated cylindrical shaped products into liquefied aluminium nitrate. This was done in order to increase the age resistance without affecting the mechanical properties. The study concluded that selection of pre-sintering temperature significantly influenced the deterioration of the implant within the pre-existing conditions that are present within the mouth. This could be improved by the selection of process conditions that are optimized. It is observed that the temperature of 1250°C for sintering provides the best “on the whole comprehensive” characteristics of ceria stabilized ZrO\(_2\) as per the dopant concentration used in the study. The fracture toughness was improved but when this happened there was a slight decrease in strength as well as LTD resistance. [1]

5.2. Ceria stabilized zirconia with calcia and alumina composites:
Tovar-Vargas et. al. have resolved the issue of inferior mechanical properties of zirconia ceramics by stabilizing with 10 mol% CeO\(_2\) and 1 mol% CaO, aided by the inclusion of \(\alpha\)-Al\(_2\)O\(_3\) as additives. (2 to 15 wt %). Improved microstructure, reduced grain size (with 2.5wt% addition), increased hardness numbers, and maximum strength with 10 wt% alumina addition were the salient findings. Resistance to crack formation and propagation were still found to be significantly higher when compared with 3Y-TZP. Further improvements were shown by increased resistance to hydrothermal degradation via alumina addition. This significant finding throws open a tremendous opportunity for using this compound for dental implant applications. [2]

5.3. Influence of spray drying slurry parameters on alumina-zirconia composites as dental implants:
Chiangka, S et. al. have studied the influence of slurry formulation on the Morphology and flowability of spray-dried alumina/zirconia composites. While zirconia is well known to possess high fracture toughness and mechanical strength, alumina and zirconia composites produced have minimal crack defects and don’t get worn out easily making it suitable for being used in orthopaedic implants. In this paper the main focus is on the effects of solid content in the slurry and the binder type on the physical characteristics of the agglomerates which are spray dried. Al\(_2\)O\(_3\)/ZrO\(_2\) composite particles were made by using alpha-alumina and 3YSZ powder as the starting materials. The composites were made with 90wt% Al\(_2\)O\(_3\) and 10wt% of the 3YSZ which were ball milled for 6 hours. 1 wt% sodium
poly acrylate was used as a dispersant to make the slurry. Polyvinyl alcohol, polyethylene glycol and mixture of Polyethylene glycol–polyvinyl alcohol (PEG-PVA) were used as agents to promote adhesion. The composite powders were spray dried and the slurry atomized under the operating conditions of 190°C inlet drying air temperature, air in the form of tiny particles were allowed to flow at 3571iter/n and slurry at 10 ml/min. The SDP was obtained and physical characteristics were measured, and analysed. The size distribution was measured using laser particle size analyzer, morphology using Scanning electron Microscope (SEM), density using tapping device and compressibility index using Carr index.

The conclusions arrived at based on the results indicated that improved characteristics of composite particles could be obtained with higher solid content in the slurry (70 wt %). The composite particles produced in this experiment showed a morphology of homogenous round shape with its average diameter measuring 39.7 microns. [3]

5.4. Load bearing capacity of YSZ dental implants:

Adatia, N. et. al. studied the ability of YSZ dental abutments(supporting structures for dental implants) to sustain load [4]. The type and material of the abutment can determine how aesthetically pleasing a dental implant can be. One such suggested choice of abutment used for aesthetically restoring a dental implant is Zirconia. The effect of reduced strength of clinical abutment assembly comprised of abutments synthesized from yttria-stabilized zirconia was determined. Next in the list is Alumina: these two are popular abutments because of the light transmittance quality, colour and high fraction resistance [5]. Though the minimum strength of an abutment is not yet defined, in general a durable, aesthetic restoration should withhold occlusal forces (forces acting on teeth, on upper and lower jaws, in contact during chewing action) in the range of 90 to 370Newtons. Unmodified Zirconia, when subjected to test till the component failed, failure occurred in the cervical region of the abutment, close to gold screw and implant platform.

Tests were conducted for thirty yttria stabilised zirconia abutments in 3 groups of ten abutments each. Group 1, 2 and 3 were tested with no modification, and with modification in dimensions. Abutments were connected to implants that were first placed with a SS cylinder with the analog (attachment mechanism in dentistry) long axis parallel to the cylinders’ long axes and that was fixed by using Field’s metal alloy. A mylar film of 0.1mm thickness was inserted between the stylus (a part of the implant structure) and abutment to control loading and to prevent un-intentional damage to the surface when loading stylus on zirconia abutment. 60° off-axis load was enabled onto the cylinder assemblies held at an angle of 30° by a stainless steel apparatus in the Universal Testing Machine along where the incisal edge was loaded vertically until failure. Abutment fracture was determined by an audible popping sound. Remaining material volumes after material loss in water and HANKS solution were calculated and the values were correlated with the associated fracture strengths.

Though preparation of zirconia did not result in any material failure, but sparks and wear in the metal bur was noticed during the preparation of Zirconia abutment, the axial reduction number for individual abutments and mean volumes of reduction were measured and calculated respectively. Irrespective of the preparation of abutment, the tested specimens displayed a consistent load-to-failure pattern consisting of four regions such as deformation of abutment, deformation of abutment screw, abutment fracture and load returning to zero after abutment fracture respectively.

Abutments were presumed to be identical. The screw present within the abutment is assumed to play a significant role in the ultimate strength. Deformation in the screw suggested that the abutment screw was the first component to be affected by the progressive loading. Adding a crown to the abutment can provide a shield to it from the effects of load and permit application of higher load prior to failure. The accumulation of micro damage during the abrasive wear damage YSZ abutment accounted for the clinical failure and strength reduction.

The conclusion of the study was that the weakest points of the abutment assemblies were the abutment/analog interface. Margin preparation up to a thickness of 1.0mm of the tested yttria stabilized zirconia abutments with irrigation (key part of implant procedure) appeared not to have significantly affected the fracture strength of the abutment assemblies. [5]
5.5. Studies on Bio-compatibility of YSZ:

Oishi, M. et. al. carried out a study on the surface changes of yttria stabilised zirconia in water and HANKS solution. The paper reports the results of studies on the influence of body fluid chemistry on YSZ disks with varying crystal growth orientations (planes). The variations in reactions taking place on 3 dissimilar YSZ disks with different crystal plane orientations were determined and reported in this paper [6].

At certain temperatures and depending on the amount of oxide (dopants) added, the incorporation of oxides such as yttria, calcium oxide and magnesium oxide in zirconium oxide stabilizers, in the tetragonal or cubic phase which exhibited superior bending strength. Immediately after loading YSZ onto a single-piece dental implant, 95% of bone integration was witnessed. Since YSZ is a bio inert ceramic it is to be surface treated to enhance its compatibility and integration with neighbouring tissues. Coating tissues containing collagen onto the surfaces of zirconia based bone implants make the implants compatible with our bodies. These coated surfaces are inclusive of hydroxyl groups that facilitate protein adsorption and tissue attachment.

10 mm × 10 mm × 0.5 mm thick YSZ plates of (100), (110) and (111) single-crystal planes containing 13 mol% Y₂O₃ were polished to < 0.5 nm roughness and cleaned twice in solvents by 5-minute ultrasonication each, analysed by using XRD with Cu Kα target (40 kV /40 mA, 2θ= 5°-140°). At ambient temperatures, the polished YSZ plates were immersed in water and HANKS Solution (used to wash cells and tissues) for a period of 1-60 days and 7 days respectively. When taken out of the solutions the YSZ specimens that were subjected to (a) water and (b) HANKS treatment were immediately washed with ultrapure water and dried in N₂ gas. The surfaces of water and HANKS treated YSZ plates with (100), (110) and (111) planes were studied by employing XPES. Reflections from certain planes got highlighted in the XRD pattern depending upon the plates with different planes. The amount of yttrium oxide in YSZ (110) was similar to the nominal composition of YSZ with 13 mol% Y₂O₃ and was less in YSZ (100) and YSZ (111) disks. Zirconium (Zr), yttrium (Y), oxygen (O), and carbon (C) were present on the surfaces of water-treated YSZ specimens, in addition to which Zr and Y were found to be present in the Zr⁴⁺ oxidized state and Y³⁺ oxidized state respectively. An increase in concentration of O and decrease in concentrations of Zr and Y was noticed in the water-treated YSZs. The proportion of hydroxyl ions and H₂O in YSZ (100) and YSZ (110) increased when subjected to water treatment for 60 days. However, in YSZ (111) water treatment for 60 days, did not alter the hydroxyl ion and H₂O contents that was similar to polished YSZ (111). Except for the presence of P in the form of phosphate ions no significant changes were seen in the composition of the surface of HANKS-treated YSZs. The valence band which is sensitive to changes in impurities and crystalline structure was recorded for all 3 specimens and presence of 2 broad peaks pertaining to the higher O 2p and lower Zr 4d bands was found to be common for all of them. Post immersion in HANKS solution, existence of phosphate was evident on the surfaces of all the specimens which facilitate the adhesion of tissues.

Towards the end of the study it was concluded that the crystalline phase structure of YSZ remains unchanged during the preliminary stage of reaction in the mouth and the associated chemical environment of the saliva, during which the hydroxyl ions (OH⁻) and P - concentrations increased on the YSZ surface which enhanced the adsorption of proteins and that the reactivity of the YSZ surface plays a major role in the adhesion of the tissue. Furthermore, the bonding of yttria-stabilized zirconia (YSZ) to the tissues were confirmed, despite the chemical non-reactivity. [6]

5.6. Accelerated ageing studies on YSZ dental implants:

Flinn, B. et. al. shares with us the accelerated aging characteristics of three yttria-stabilized tetragonal zirconia polycrystalline dental materials in this research paper [7]. The paper focuses on determining the effect of accelerated hydro-thermal aging on the flexural strength of 3 commercially available 0.2 mm bars of Y-TZP materials by using a 4- point bending test. Since Yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) offer aesthetic advantages, and are tougher and more biocompatible than traditionally used materials for ceramic restorations, they are the most preferred alternative for the dental implant abutments which are in direct contact with the gingival tissue. Despite of all the above mentioned advantages, long term degradation (LTD) or aging
associated with the spontaneous transformation of the metastable tetragonal phase to the monoclinic phase of Y-TZP has been a major topic of concern. From studies it has been proved the decrease in mechanical properties of the Y-TZP by surface roughening, grain pull out, and micro cracking as a result of rapid transformation from tetragonal zirconia to monoclinic zirconia phase. The combined influence of stresses, temperature, acids, humidity, and saliva in the oral environment on the transformation of Y-TZP from tetragonal to monoclinic zirconia phase, when tetragonal zirconia is exposed to elevated temperatures around 250°C and/or aqueous environments is not clearly understood. However, it has been proved that tetragonal to monoclinic zirconia transformation produces stresses at the crack tips which further enhance unstructured transformations in neighbouring grains and due to the associated volume change further increases the stresses around them. This produces micro-cracking leading to a formation of passage to allow moisture diffusion into the implant.

Green slabs of Y-TZP from 3 different suppliers were subjected to sintering to manufacturer specifications. 30 thin bars, each of dimensions 22 × 3 × 0.2 mm were diamond sectioned out of these slabs and were ground by using diamond wheels. The surfaces of the slabs were studied to assess the uniformity in the grinding methodologies. 5 experimental specimens per group at 50, 100, 150, and 200 hours were subjected to artificial aging at standard autoclave sterilization conditions. To perform aging, specimens were suspended in water under in a pressure chamber that was kept in a furnace with preset temperature and pressure conditions. The furnace was heated to desired temperature and time. The phase transformation from t-ZrO₂ to m-ZrO₂ that occurred due to accelerated aging was studied via X-ray diffraction. Peak intensities at 2θ = 28° and 30° were considered. The volume fraction of t-ZrO₂ to m-ZrO₂ phases were calculated according to the Garvie-Nicholson method [8]. The fracture strength of each specimen was measured in flexure in a universal testing machine by using a 4-point fully articulated bending fixture with 10 mm inner span and 20 mm outer span dimensions. The specimen thickness was chosen based on the minimum thickness of 0.3 mm of Y-TZP dental restorations. Microstructure and fracture surface studies were carried out by employing a FESEM.

Data were analysed as a function of aging time. Fracture surface studies on the aged specimen were carried out to understand the influence of the phase transformation. Similar studies were performed on specimen even after the mechanical strength test (Flexural). Absence of m-ZrO₂ phase prior to aging, and an increase after initial hours of aging was found, which confirmed the occurrence of phase transformation. The mean flexural strength reduced with increased m-ZrO₂ content. A distinct deposit of transformed material of thickness between <2 µm and 60 µm was visible in SEM. Corresponding to the quantity of m-ZrO₂ content, and the layer thickness, aging reduced the mechanical strength. Presence of micro cracks was evident on the transformed surface layer. The fracture strength was found to decrease with the larger transformed layer width. However, the flexural strength of all specimen that was aged 40 times more than the standard aging period. Since many of the occlusal force related parameters are not considered in the study, long duration analysis i.e. above 5 years, of prospective clinical studies to evaluate such restorations may provide an actual understanding of Y-TZP behaviour in the local physiological environment (in dentistry) with reference to LTD.

Though the Null hypothesis stated that the accelerated aging would not weaken the Y-TZP, a significant reduction in the mean flexural strength of 3 brands of commercial zirconia due to LTD was noticed. [7]

5.7. Zirconia based coatings as reinforcements for dental implants:

Fu et. al have discussed the role of Zirconia (ZrO₂) that is used as a reinforcement due to its high strength and stress induced phase transformation toughening. This material usually displays less effect of amorphization and dissociation’s and is more thermal resilient and hence is not affected by high plasma temperature during coating process. In this study 30 wt % YSZ (8%YSZ)-HA (70%) composite coatings were synthesized to obtain well bonded coatings on Ti-6Al-4V. To observe the influence of zirconia used as reinforcement on HA, coatings of fine 8YSZ coating on Hydroxy Apatite (HA) composite powder was prepared using a slurry method and then by plasma spray drying. In this
study the influence of the plasma spraying energy on various factors such as phase composition, crystallinity, microstructure, heat treatment and mechanical properties was investigated. The mechanical properties were found to highly improve by the composite HA coatings.

The results from XRD showed the presence of a diffused background due to the amorphous phase and sharp peaks showing presence of Zirconia, crystalline HA, Calcium Oxide, Tetra calcium phosphate (TTCP) and tricalcium phosphate (TCP). It can be concluded that with addition of YSZ crystallinity decreases as crystalline HA transforms into amorphous calcium phosphate. The fourier transform infrared spectroscopy (FTIR) graph shows that during plasma spraying HA has undergone dehydration and crystallinity of HA decreases and amorphous calcium phosphate forms. It is also noticed that increasing the plasma net energy enhances the temperature of plasma flame which intensifies powders heating (plasma net energy used - 15kW). With an increase in plasma net energy powder the molten state of powder was improved as almost all HA particles were melted. The morphology of the composite was a combination of partial and fully melted YSZ within HA. With heat treatment the change of amorphous, TCP & TTCP to crystalline HA was possible. Plasma spraying of YSZ and HA solid solution improved the mechanical properties. With increase in plasma net energy and addition of zirconia there was a significant improvement in mechanical properties. The tensile strength test concluded that the source of the weakness was the unmelted YSZ. Therefore, for maximum reinforcement uniform or complete melting of YSZ is required. [9]

6. Conclusions
This paper has attempted to present a comprehensive review of the most popular dental implant materials such as 3 and 8% yttria stabilized zirconia, ceria stabilized zirconia, processing methodologies involving spray dryer to synthesize free flowing agglomerates of nano powders and some of the characterisation techniques involved with specific reference to dental implant applications.

7. References
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