Global Scientific JOURNALS

GSJ: Volume 5, Issue 8, August 2017, Online: ISSN 2320-9186
www.globalscientificjournal.com

SYNTHESIS OF 3YSZ NANOPOWDERS BY CO-PRECIPITATION METHOD AND INVESTIGATION OF INFLUENCE OF PROPANOL ON AGGLOMERATION STATE

Pratima.S.Joshi[1],Dr.S.B.Patil[2]

1.PG Scholar,Department of Material Science & Technology,PDACE,Kalaburagi,Karnataka

2.PG Co-ordinator,Assitant Professor,Department of Material Science & Technology,PDACE,Kalaburagi,Karnataka

Abstract

Partially stabilized zirconia is known for its superior mechanical properties such as high hardness and toughness.Partially stabilized zirconia are prepared by adding stabilizers such as CaO,MgO,Y_2O_3 and CeO_2 in monoclinic zirconia.However,due to aesthetic application for dental prosthesis,yttria partially stabilized zirconia have been of great interest.The synthesis of 3YSZ by coprecipitation process that is washed with water resulted in agglomerated nanopowders that inhibit sinterability.To enhance sinterability the nanopowders needs to be deagglomerated.Also it has been reported that washing of water washed coprecipitated mass of yttrium-zirconium hydroxide with solvents such as methanol,ethanol, propanol and butanol reduces the extent of agglomeration. In addition to the washingmedium, drying temperature also significantly influences the agglomeration state of YSZ.Already it has been worked on the agglomeration state of 3YSZ nanopowders washed with ethanol.Hence an attempt has been made to wash with varying amount ofpropanol to reduce the agglomeration state of 3YSZ nanopowders.

Influence of propanol treatment ofco-precipitated yttrium–zirconium hydroxide on agglomeration of calcined nano 3YSZ powder was studied. Nanocrystalline 3YSZ (3 mol% yttria stabilized zirconia) powders

were synthesized through co-precipitation followed by washing with propanol and calcination at different temperatures in the range of 100˚–500 °C. Results indicated that the amount of propanol used in washing the zirconium hydroxide precipitate had a significant impact on the calcined powder characteristics. Different ratios of propanol to the water contained within the precipitate were used during washing and the calcined nano 3YSZ powders were characterized in terms of tap density, green density and FTIR(Fourier Transform Infrared Spectroscopy) .The other characterization techniques such as X-ray diffraction(XRD),Thermo-gravimetric-Differential thermal analysis(TG-DTA),Transmission electron microscope(TEM) has been also carried.
The results indicated that a minimum propanol amount of 2–3 times that of water in the precipitate was required to achieve superior agglomeration state of the calcined 3YSZ nanopowders. The nanopowders obtained by washing with optimum propanol amount resulted in high green density of compact and lower tap density with high volume occupancy of nanopowders when tapped.Agglomeration state of the calcined 3YSZ nanopowders attainment with varying volume% of powder characteristics was studied. The results revealed influence of varying amount of propanol on 3YSZ nanopowders reduced the agglomeration state of nanoparticles.The 1:4 ratio of 3YSZ precipitate washed with propanol amount showed the good agglomeration state of nanoparticles.

Keywords:3YSZ(3mol% yttria stabilized zirconia),Co-precipitation method,Agglomeration,Temperature,Powders

1.Introduction:

Zirconia ceramics have received a lot of attention from researchers due to their unique properties associated with different crystalline forms. Zirconia stabilized in tetragonal form is suited for structural applications owing to its high fracture toughness, strength whereas
zirconia stabilized in cubic form has been used in fuel cells, sensors etc. because of its high oxygen ion conductivity and phase stability[1-38].Besides the inherently high fracture toughness of the tetragonal phase, higher strengths in tetragonal zirconia have been achieved by producing submicrometer size grains in highly dense sintered ceramics.To achieve this, the starting powder particles have to be in the nanoscale (<100 nm) so that on consolidation and sintering they attain high densification with submicrometer grain size. Over the years many approaches have been developed for synthesis of partially or fully stabilized nanocrystalline zirconia ceramics but controlling the state agglomeration in nanocrystalline powders has remained a challenge. The extent of agglomeration in nanoceramic materials has been seen to be a function of the synthesis route including the temperature of calcinations of amorphous

intermediates which result in crystallization. Hydrothermal synthesis typically does not involve high temperature calcinations and thus results in lower extent of agglomeration of particles[1-11]. Zirconia is a white powdered material commonly used to produce dental frameworks for dental substructures such as crowns, bridges, etc. Unlike standard ceramics that tend to be brittle and hard, Zirconia has excellent wear resistance and strength, and comes with a flexibility which is far better than those of other technical ceramics.Pure zirconium dioxide undergoes a phase transformation from monoclinic (stable at room temperature) to tetragonal (at about 1173 °C) and then to cubic (at about 2370 °C), according to the scheme(Figure 1).

Monoclinic(1173 °C)→Tetragonal(2370 °C) → Cubic (2680 °C)→ Melt

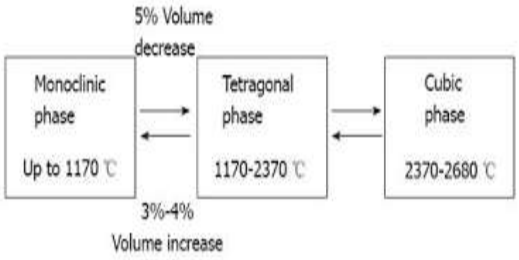

Figure 1:Phase transformation of Zirconia

Nanocrystalline zirconia has been synthesized by various chemical routes but among them coprecipitation method has been popular as it can be scaled up,using low-cost accessories. In this method, the step of driving away water from coprecipitated mass, forces theparticles to agglomerate. The follow-up step of high temperature treatment (crystallization) leads to further enhancement and strengthening of agglomerates.[12-35].Heuer et al.[36] reported that during drying of the coprecipitated mass, high surface tension of water (73 mN/m) is responsible for bringing the zirconium hydroxide nanoparticles closer resulting in hard agglomerates. If ethanol is used for surface treatment of zirconium hydroxide precipitate, the extent of agglomeration reduces considerably because of its low surface tension (24 mN/m). On drying, particles are not forced together and the hydroxyl bridging as encountered in case of water-washed powder is missing and hence result in lower degree of agglomeration.[39-53].Wang et al.[48] reported the synthesis of zirconia with 80% of ethanol added after dissolution of $ZrOCl_2.8H_2O$ in minimum water to get rid of agglomeration problem to a considerable extent. In his work12 10 mol% $MgO–ZrO_2$ was synthesized by coprecipitation by using mixed solvent (water and ethanol)
and pure ethanol. In both cases the final precipitate was washed with absolute ethanol.Initial studies by the present authors while confirming the prior observations that ethanol washing
contributes to deagglomeration suggested that amount of ethanol used in washing of coprecipitated mass may have a role in

determining calcined (crystalline) powder characteristics, however, the aspect of washing with Propanol as not been reported in the literature. H.G.Scott et.al[33] worked on Phase relationships in the zirconia—yttria system wherein the
Metastable and Equilibrium phase relationships in the system ZrO_2:$YO_{1.5}$ have been studied by X-ray diffraction.The conditions for the retention of a zirconia-rich tetragonal phase at ambient temperature are established.The existence of a miscibility gap,closed below the solidus temperature,in the yttria-rich solid solution region is proposed.some evidence for partially ordered phases is presented. Mary Sue Kaliszewski & Arthur H. Heuer et.al[38] worked on the Alcohol interaction with zirconia powders wherein the mechanism by which alcohol washing of ceramic powders produces "soft" agglomerates has been investigated by studying the interaction of ethanol with hydrous ZrO_2 powders using Fourier transform infrared (FTIR) spectroscopy.
Unambiguous evidence of ethoxide formation has been found, which apparently prevents bond formation between adjacent particles and thus the formation of "hard" agglomerates

2.Experimental Method:Co-Precipitation Method is used for synthesis,it is a phenomenon where a solute that would normally remain dissolved in a solution precipitates out on a carrier that forces it to bind together,rather than remaining dispersed.The simultaneous precipitation of more than one componenet(Figure 2).

Figure 2:Flow chart of Co-precipitation method

Materials used:

- Zirconium Oxychloride(Mincometsal,Bangalore)(99.9% purity)
- Yttrium nitrate(99.9% purity)
- Ammonia(25% concentrated)
- Distilled water
- 2propanol(99.9%purity(GC),Water(≤ 0.5%))

.

Synthesis Process: Synthesis of 3 mol% yttria–stabilized zirconia was carried out by reverse-strike coprecipitation method followed by drying and calcination of the coprecipitated mass at temperatures that is, 100°C to 500˚C by varying volume%.

Precursor solutions of 0.5 M zirconium oxychloride were prepared in double distilled water using magnetic stirrer. Yttrium nitrate solution was also prepared. Zirconium and yttrium-containing precursor solution was prepared by adding an appropriate amount of yttrium nitrate solution to zirconium oxychloride solution(1:1 ratio) to achieve 3 mol% yttria with zirconia in the calcined mass. The prepared precursor solution was added drop wise into a continuously stirred ammonia solution ensuring the pH remained above 10 till complete addition of precursor solution to ammonia. Stirring was continued for 2 h after complete addition of precursor solution into ammonia. The precipitate was left overnight to settle (~12 h) and then filtered on fabric cloth for the removal of excess ammonia. This precipitate was subjected to washing with distilled water by addition of measured quantity of water and stirring for 30 min. The precipitate was left to settle for 3 h and then filtered on fabric cloth.

The washing procedure was repeated seven times till Cl^- ion was completely removed from the precipitate. The absence of Cl^- ion was confirmed by absence of AgCl precipitate up on addition of 0.1 N $AgNO_3$solution to the filtrate.Water-washed precipitate was divided into seven parts.One part was taken as it is and the crystalline powder obtained on its calcination is referred to as waterwashed powder. The other six parts of the precipitate were washed with different amounts of propanol. Quantity of propanol was chosen in reference to the quantity of water present in the precipitate. Water associatedwith the washed and filtered coprecipitated mass was determined by drying known quantity of coprecipitated mass at 100°C. Following the last wash and after having been kept on the filter cloth for 12 h, the amount of water in the precipitate was reproducibly seen to be around 93% of the filtered coprecipitated mass. During washing and filtration of the precipitate the conditions in the entire study were maintained such that greater than 90% water was retained in the precipitate to facilitate its mixing in propanol and displacement of water with propanol.Propanol amount used for washing the precipitate was varied in the ratio of 1:1, 1:2, 1:3, 1:4, and 1:5 (water: propanol) with respect to the water associated with the precipitate and calcined at temperatures 100˚C,200˚C,300˚C,400˚C and 500˚C(Figure 3).

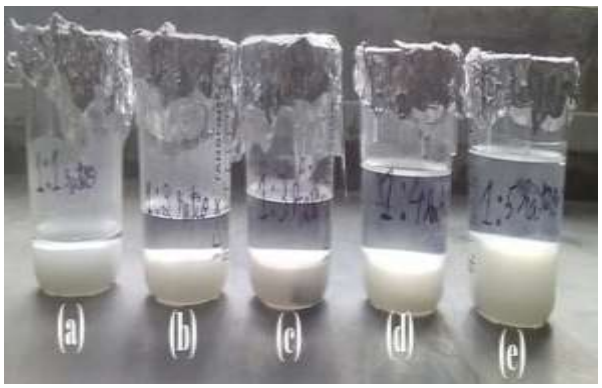

Figure 3 :3YSZ precipitate washed with propanol (a)1:1 ratio,(b)1:2 ratio,(c)1:3ratio,(d)1:4 ratio and (e)1:5 ratio

(the propanol amount used for washing the precipitate was varied with the varying volume% with respect to the water associated with the precipitate)

The precipitate was washed with each of the propanol amount twice followed by drying at 100°C. The dried precipitate was calcined at 200°C ,300°C ,400˚C and 500˚C separately for each of the powders washed with different propanol amounts. In the remaining text, zirconium hydroxide precipitate refers to the precipitate with composition expected to yield crystalline 3 mol% yttria stabilized zirconia (3YSZ) upon calcination. Also, water-washed precipitate refers to chloride-free precipitate. Water-washed and propanol-washed powders refer to crystalline 3YSZ powder obtained by calcination of water-washed and propanol-washed precipitate.

Results and discussion:

1.XRD(X-ray diffraction analysis):

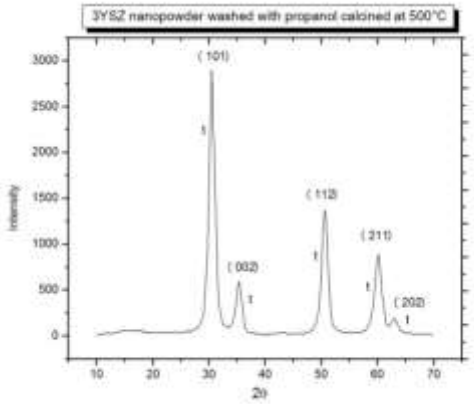

Figure 4 :XRD patterns for 3YSZ nanocrystalline powders wherein the precipitate was washed with propanol that was calcined at 500˚C

All the 3mol% YSZ samples prepared in the study predominantly are of tetragonal as shown in figure above 4.The miller indices of 3YSZ nanocrystalline powders wherein the precipitate washed with propanol calcined at 500˚C are (1 0 1),(0 0 2),(1 1 2), (211) and (2 0 2).This miller indices pertains to tetragonal 3YSZ structure wherein no monoclinic phase observed in the XRD.

2.TGA-DTA(Thermogravimetric Analysis-Differential thermal Analysis):

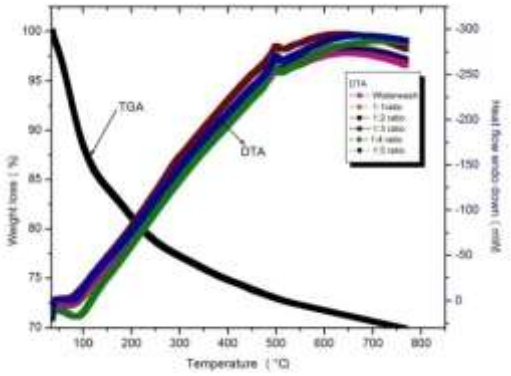

Figure 5.:TGA-DTA of precipitate that was washed with water followed by propanol washing (1:0,(Waterwash)1:1,1:2,1:3,1:4 and 1:5 water:propanol ratio) calcined at 100˚C

The TGA-DTA carried for 3YSZ nanocrystalline powders produced by Propanol waterwash(1:0,1:1, 1:2,1:3,1:4 &

1:.5 (water to propanol ratio)) that were calcined at 100˚C and 500˚C.The TGA-DTA graphs explain about exothermic peak in figure 5.TGA-DTA showed the presence of amorphous and attainment of crystalline peaks for 100˚C wherein for 1:0ratio(waterwash)=498.30˚C, 1:1ratio =499.44˚C, 1:2 ratio =499.59˚C, 1:3 ratio =498.08˚C, 1:4 ratio =493.69˚C and 1:5 ratio =498.62˚C with fast rate of heating from 40˚C to 750˚C at 20˚C/min and TGA-DTA also carried for powders calcined at 500˚C.The adsorbed propanol evaporates at 82.6˚C with autoignition temperature of 399˚C.Hence there are no exothermic peaks for the powders calcined at 500˚C.The adsorbed propanol cannot be detected in 500˚C calcined powders.

3.TEM(Transmission Electron Microscopy):

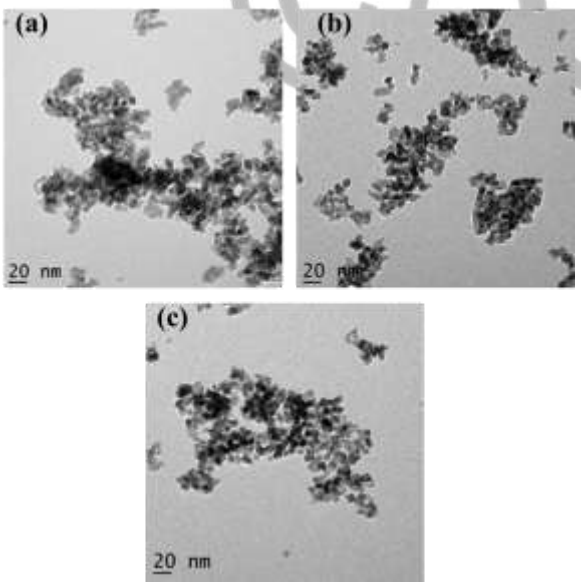

Figure 6:TEM image of 3YSZ nanocrystalline powders calcined at 500°C powder produced by washing with propanol (a)1:2 ratio,(b)1:4ratio and (c)1:5 ratio

The TEM micrographs are for 3YSZ powders calcined at 500˚C.These powders were washed with propanol.The propanol used for washing is varied with water:propanol ratio in 1:0(waterwash),1:1,1:2,1:3,1:4 and 1:5.The TEM micrographs showed for calcined powder (figure 6) for 1:2,1:4 and 1:5 ratio.The TEM shown in figure 6 reveals that the size of primary particles are in the range of 5-20nm.

4.CHN analysis(Carbon,Hydrogen and Nitrogen): The CHN analysis is carried for to detect the presence of %C and %H in the samples.As the work is done on 3YSZ nanopowder washed with varying volume% of propanol at different calcinations temperatures.The CHN analysis is done for 3YSZ nanopowder washed with varying volume% of propanol calcined at 100˚C.The propanol structure is as shown below:

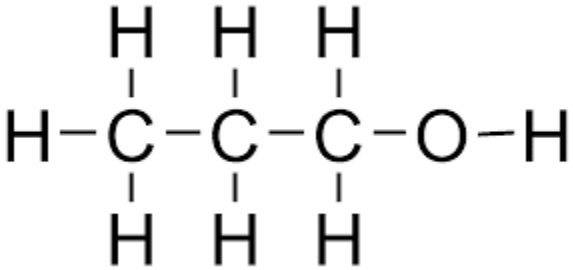

Figure 7: Structure of 2-propanol

The 2-propanol contains the Carbon and Hydrogen due to which the presence of adsorbed propanol on the 3YSZ nanopowders washed with varying volume%

amount of propanol calcined at 100˚C is calculated with CHN analysis.The CHN anlaysis for agglomeration state of nanoparticles is discussed.

Sample No	Sample Name	C%	H%	Sample Weight, mg
1	**100 Degree Waterwash PPT**	1.24	0.89	6.06
2	**100 Degree Propanol1-1**	1.07	1.26	6.78
3	**100 Degree Propanol1-2**	1.52	1.52	7.10
4	**100 Degree Propanol1-3**	1.34	1.53	6.73
5	**100 Degree Propanol1-4**	1.02	1.86	7.16
6	**100 Degree Propanol1-5**	1.18	1.67	6.71

Table 1:CHN Analysis results for samples

The Table 1 listed above explains about CHN analysis.The adsorption of propanol on 3YSZ precipitate calcined at 100˚C samples carried out.Due to varying weight of samples taken by STICcochin wherein the presence of C% and H% cannot be attained for agglomeration state of nanoparticles.The %C and %H shows adsorbed propanol on 3YSZ precipitate washed with it. The CHN analysis results varied with 3YSZ precipitate washed with varying volume% of propanol was not appreciable. This proves the fact that tap density and green density is to be carried out for achieving best possible degree of aggalomeration state of nanoparticles.The samples are of calcined at 100˚C.

5.Tap Density: Tap density is obtained by mechanically tapping a graduated cylinder containing the sample until little further volume change is observed. Tap density for 3YSZ nanopowders calcined at 100˚C is discussed.

Figure 8: Volume occupied upon tapping by 3YSZ powders calcined at 100°C wherein the precipitate were washed with water and different amounts of propanol; Water-washed powder (a) and propanol-washed powders (b) 1:1 (c) 1:2 (d) 1:3 (e) 1:4 & (f) 1:5 water to propanol amount ratio.

Table 2:Tap density of 3YSZ nanopwders by the coprecipitated mass washed with varying volume% propanol calcined at 100˚C.

Sl.no	Water:Propanol Ratio	Tap Density(g/cc)
1.	Waterwash(1:0)	1.041
2.	1:1	0.86
3.	1:2	0.83
4.	1:3	0.71
5.	1:4	0.55
6.	1:5	0.55

It is known that agglomerates of different sizes lead to different extents of packing. The differences in packing behavior of water washed powder and powders washed with different propanol amounts were characterized by measuring tap density. The tap density measurements revealed that the powder obtained by calcination of water-washed precipitate occupied the least volume (shown in Figure 8)and hence highest apparent density of 1.041g/cc due to presence of large dense aggregates. For 3YSZ nanopowders washed with varying volume% propanol at 1:1ratio,1:2ratio,1:3ratio,1:4ratioand 1:5 ratio(water of precipitate to propanol) ratio the tap density decreased to 0.86g/cc,0.83g/cc,0.71g/cc,0.55g/cc and 0.55 g/cc respectively. This decrease in tap density indicated that increase in propanol amount in washing of the precipitate results in a fluffy mass and hence increased volume occupancy (refer Figure 8) and lower tap density. On increasing the propanol amount for washing of the precipitate to 1:5 water to propanol ratio the calcined powder occupied larger volume and thus had the least tap density of 0.55g/cc suggesting presence of voids greater than 80%.For further increase in propanol amount while washing the precipitate the calcined powder volume (tapped) remained same. These observations indicated presence of larger, denser agglomerates in water washed powders and smaller agglomerates in powders obtained by washing with 2.5 times or greater propanol amount(Table 2).

6.Green density: The green density is of before sintering stage.Green density values for 3YSZ nanopowders by the coprecipitated mass washed with varying volume% propanol calcined at 100˚C is discussed.

Table 3:Green density of 3YSZ nanopwders by the coprecipitated mass washed with varying volume% propanol calcined at 100˚C

Sl.no	Water:Propanol Ratio	Green density(%TD)	Green density(g/cc)
1.	Waterwash(1:0)	36	2.18
2.	1:1	36	2.19
3.	1:2	39	2.36
4.	1:3	40	2.42
5.	1:4	41	2.44
6.	1:5	41	2.44

The powders that were calcined at different temperatures were compacted uniaxially at 200MPa.Pellets are produced by without any binders with the identical weight of 1gm(Figure 9).

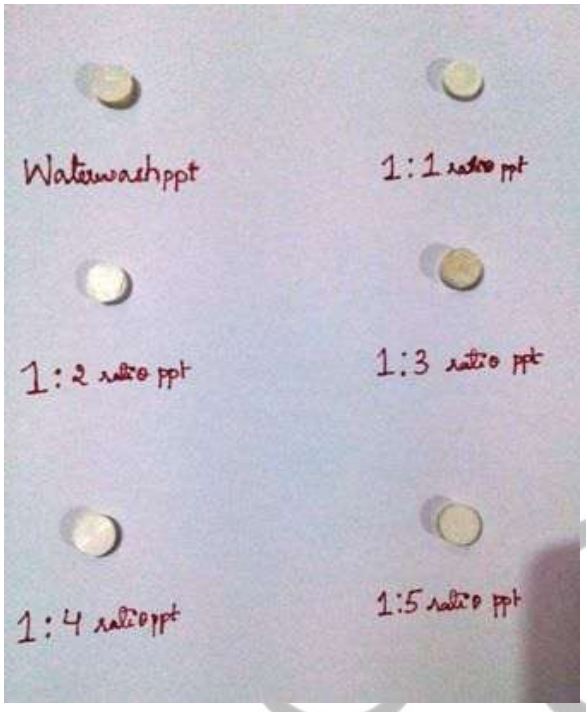

Figure 9: Pellets produced from3YSZ nanopowders by the coprecipitated mass washed with varying volume% propanol calcined at 100˚C on hydraulic press machine

The pellets are of 3YSZ nanopowders produced by the coprecipitated mass1:0(Waterwash),1:1,1:2,1:3,1:4 and 1:5 calcined at 100˚C.Hence the green density is listed in above table 3.The green density goes on increasing and gets stable after 1:4 as with the volume variation the identical weight of 1gm taken.From table it shows that the green density is increasing and getting stable after 1:4 precipitate washed with propanol.It is worth to note that the propanol washed powders which had the least tap density showed the highest green density(41% of Theoretical density) when powders compacted uniaxially at 200MPa.The waterwashed powder with highest tap density showed the lowest green density in the compacted state(36%Theoretical density).From green density values the 1:4 is the best for agglomeration state of nanoparticles.

7. **FTIR (Fourier Transform Infrared Spectroscopy)Analysis**:

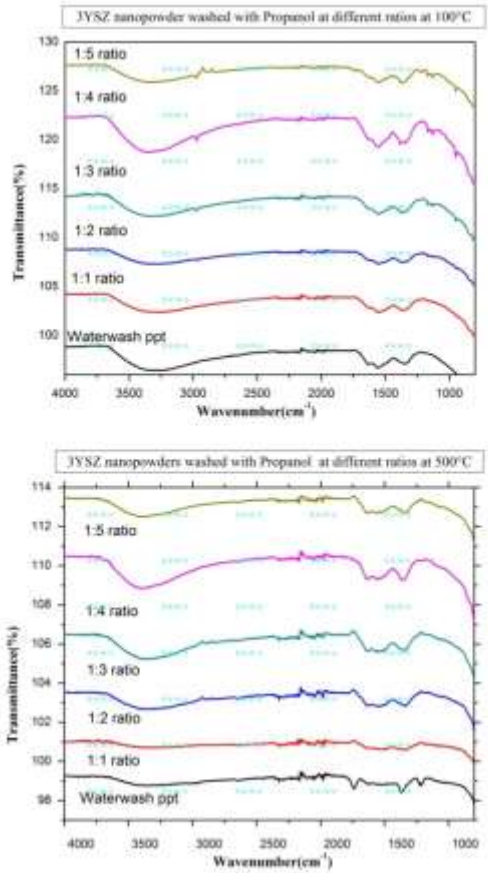

Figure 10:FTIR graph of 3YSZ nanopowder washed with propanol calcined at 100˚C and 500˚C(a)1:0ratio(Water Wash),(b)1:1

ratio,(c)1:2 ratio,(d)1:3 ratio,(e)1:4 ratio and (f)1:5 ratio

The FTIR of 3YSZ nanopowders washed with propanol calcined at 100˚C and 500˚C is studied.The some amount of chemisorbed propanol on the 3YSZ precipitate washed with varying volume% of propanol is studied.The Table listed below 7.6 explains about functional group with stretch.

Table 4:The transmittance with functional group occurred in 3YSZ nanopowder washed with varying volume% of propanol calcined at 100˚C and 500˚C.

Sl.no	Transmittion(cm^{-1})	Functional group
1.	3000-3800	O-H
2.	3000-2900	C-H
3.	1580-1080	C-O
4.	1160-1070	C-O
5.	1250-900	C-H

FTIR spectra of 3YSZ nanopowders by the coprecipitated mass washed with varying volume% propanol calcined at 100˚C and 500˚C obtained as shown in figure 7.6.The table 7.6 explains about functional group stretch and transmittance(%) at ($3800cm^{-1}$-$3000cm^{-1}$) are due to O-H stretch, the two peaks at ($3000cm^{-1}$-$2900cm^{-1}$) and (1250 cm^{-1}-$900cm^{-1}$)are due to C-H stretch and the two peaks at ($1160cm^{-1}$-$1070cm^{-1}$) and ($1580cm^{-1}$-$1080cm^{-1}$) are due to C-O stretch due to some amount of chemisorbed propanol.The figure shows the bonds of the 3YSZ precipitate washed with varying volume% of propanol[35 and 43].From figure 10 the clear indication of O-H stretch, C-H stretch and C-O stretch can be notified as the nanopowders are calcined at 100˚C(other propanol and propoxide peaks cannot be resolved because of overlap with water and carbondioxide bands).There is only presence of O-H stretch and C-O stretch in 3YSZ nanopowders washed with varying volume % propanol calcined at 500˚C.Due to evaporation of propanol at 82.6˚C the chemisorbed propanol on 3YSZ nanopowders calcined at 500˚C ,the C-H stretch cannot be detected in 3YSZ nanopowders washed with varying volume % of propanol calcined at 500˚C as shown in figure 10. So,from graphs it clearly indicates that there is presence of organic compounds,C-H stretch present in propanol adsorbed on Zr-OH(Zirconium hydroxide precipitate) ,this shows the agglomeration state of nanoparticles.

CONCLUSION & FUTURE SCOPE

Agglomeration state of nanoparticles attained with steady volume in calcined nano YSZ powders improved with increase in amount of propanol used for washing of the yttrium–zirconium hydroxide precipitate. Presence of adsorbed propanol on the yttrium–zirconium hydroxide was confirmed through Tap density,Green density and FTIR(Fourier Transform infrared spectroscopy) has been evaluated.The water present in the precipitate was required to reduce extent of agglomeration considerably in the calcined powders at 100˚C and 500˚C are studied.

XRD study showed that the samples are of tetragonal phase as with of JCPDS(Joint Committee of Powder Diffraction Society)

in with respective Miller indices(101),(202),(112),(211) and (202) which shows the tetragonal phase of 3YSZ,their is no presence of monoclinic phase.TGA-DTA showed the presence of amorphous and attainment of crystalline at peaks for 100˚C wherein for 1:0(waterwash)=498.30˚C, 1:1=499.44˚C, 1:2=499.59˚C, 1:3=498.08˚C, 1:4=493.69˚C and 1:5=498.62˚C with fast rate of heating from 40˚C to 750˚C at 20˚C/min and TGA-DTA also carried for powders calcined at 500˚C there are no exothermic peaks observed due to evaporation of propanol as it evaporates at 82.6˚C with autoignition temperature of 399˚C.The adsorbed propanol didn't detected in 500˚C calcined powders.TEM results showed the morphology and particle size of Zirconia nanoparticles with respect to agglomeration state of nanoparticlesIt can be seen from TEM images that particle size increased with increase in varying volume % of propanol when added. CHN analysis showed the C%, H% & N% in the nanopowders,wherein varying sample weights of powders of 100˚C didn't attained the deagglomeration of nanoparticles with varying volume% of propanol influence.The Tap Density showed the best when there is increase in flow character for nanopowders washed with propanol at 1:0ratio(waterwash), 1:1ratio,1:2ratio,1:3ratio,1:4ratioand 1:5ratio(water of precipitate to propanol ratio), the tap density decreased and increase in volume occupancy observed as 1.041g/cc,0.86g/cc,0.83g/cc,0.71g/cc,0.55g/cc and 0.55 g/cc respectively. This decrease in tap density indicated that increase in varying volume % of propanol amount in washing of the precipitate results ina fluffy mass and hence increased volume occupancy and lower tap density. On increasing the propanol amount for washing of the precipitate to 1:4 water to propanol ratio the calcined powder occupied larger volume and thus had the accurate tap density of 0.5568 g/cc suggesting presence of voids greater than 80%.For further increase in propanol amount while washing the precipitate the calcined powder volume (tapped) remained same. These observations indicated presence of larger, denser agglomerates in water washed powders and smaller agglomerates in powders obtained by washing with 2.5 times or greater propanol amount.The Green density shows the superior particle packing as there is increase in the green density and getting stabled from the results.The green density(%Theoretical density by taking 6.06g/cc) and green density(g/cc) for 1:0(Water wash) is 36(%TD) and 2.18g/cc,1:1 washed with propanol ppt is 36(%TD) and 2.19g/cc,1:2 washed with propanol ppt is 39(%TD) and 2.36g/cc,1:3 washed with propanol ppt is 40(%TD) and 2.42g/cc,1:4 washed with propanol ppt is 41(%TD) and 2.44(g/cc) and for 1:5 washed with propanol ppt is 31(%TD) and 2.44g/cc carried for 100˚C calcined powders uniaxially compacted at 200MPa. Hence nanopowder washed with varying volume%

of propanol shows the agglomeration state of nanoparticles in green compacts. The green density goes on increasing and gets stable after 1:4 as with the volume variation the identical weight of 1gm taken.Hence from this 1:4washed ppt with propanol is the best for agglomeration state of nanoparticles.These observations of tap density and green density pointed towards the role of propanol amount used in washing the precipitate on influencing calcined powder characteristics.

FTIR spectra of 3YSZ nanopowders by the coprecipitated mass washed with varying volume% propanol calcined at 100˚C and 500˚C.The functional group stretch and transmittance(%) at ($3800cm^{-1}$-$3000cm^{-1}$) are due to O-H stretch, the two peaks at ($3000cm^{-1}$-$2900cm^{-1}$) and ($1250\ cm^{-1}$-$900cm^{-1}$)are due to C-H stretch and the two peaks at ($1160cm^{-1}$-$1070cm^{-1}$) and ($1580cm^{-1}$-$1080cm^{-1}$) are due to C-O stretch due to some amount of chemisorbed propanol.The figure shows the bonds of the 3YSZ precipitate washed with varying volume% of propanol.The clear indication of O-H stretch, C-H stretch and C-O stretch can be notified as the nanopowders are calcined at 100˚C(other propanol and propoxide peaks cannot be resolved because of overlap with water and carbondioxide bands).There is only presence of O-H stretch and C-O stretch in 3YSZ nanopowders washed with varying volume % propanol calcined at 500˚C.Due to evaporation of propanol at 82.6˚C the chemisorbed propanol on 3YSZ nanopowders calcined at 500˚C ,the C-H stretch cannot be detected in 3YSZ nanopowders washed with varying volume % of propanol calcined at 500˚C . So,from graphs it clearly indicates that there is presence of organic compounds,C-H stretch present in propanol adsorbed on Zr-OH(Zirconium hydroxide precipitate) ,this shows the agglomeration state of nanoparticles.

Hence 3mol% partially YSZ agglomerated state of nanoparticles synthesized by co-precipitation method with influence of propanol volume variation of powder characteristics.

Further the composites of Zirconia as a matrix can also be prepared & the results such as Tensile,Impact,Hardness,Wear Studies can be carried out.

REFERENCES

1. J.A.Navio,M.C.Hidalgo,G.Colon,S.G. Botta and M.I.Litter,"PREPARATION AND PHYSICOCHEMCIAL PROPERTIES OF ZrO_2 AND Fe/ZrO_2 PREPARED BY A SOL-GEL TECHNIQUE",Journal of American Chemical Society,Langmuir (2001),17,Page No:202-210.
2. C.Suciu,L.Gagea,A.C.Hoffmann and M.Mocean,"SOL-GEL PRODUCTION OF ZIRCONIA NANOPARTICLES WITH A NEW ORGANIC PRECURSOR",Chemical Engineering Science,61(2006),Page No:7831-7835.
3. Chih-Wei Kuo,Yueh-Hsun Lee,I-Ming Hung,Moo-Chin Wang,Shaw-Bing

Wen,Kuan-Zong Fung,Chi-Jen Shih,"CRYSTALLIZATION KINETICS AND GROWTH MECHANISM OF 8mol% YTTRIA-STABILIZED ZIRCONIA(8YSZ) NANO-POWDERS PREPARED BY A SOL-GEL PROCESS",Journal of Alloys and Compounds,453(2008),Page No:470-475.

4. Masatomo Yashima,Katsuya.Ohtake,Mastao Kakihana and Masahiro Yoshimura," SYNTHESIS OF METASTABLE TETRAGONAL(T')ZIRCONIA-CERIA SOLID SOLUTIONS BY THE POLYMERIZED COMPLEX METHOD",Journal of American ceramic society 77[10],Page No:2773-2776(1994).
5. Xianshuang Xin,Zhe Lu,Xiqiang Huang,Xueqing Sha,Yaohui Zhang and Wenhui Su," INFLUENCE OF SYNTHESIS ROUTES ON THE PERFORMANCE FROM WEAKELY AGGLOMERATED YTTRIA-STABILIZED ZIRCONIA NANOMATERIALS",Materials Research bulletin 41,Page No:1319=1329(2006).
6. R.Nitsche,M.Rodewald,G.Skandan,H. Fuess and H.Hahn," HRTEM STUDY OF NANOCRYSTALLINE ZIRCONIA POWDERS",Nanostructured Materials 7[5],Page No:535-546(1996).
7. T.Mitsuhashi,M.Ichihara and U.Tatsuke," CHARACTERIZATION AND STABILIZATION OF METASTABLE TETRAGONAL ZrO_2",Journal of American Ceramic Society,Page No:97-101(1973).
8. Shigeyuki Somiya and Tokuji Akiba,"HYDROTHERMAL ZIRCONIA POWDERS:A BIBLIOGRAPHY",Journal of the European Ceramic Society,19(1999),Page No:81-87.
9. Federica Bondioli,Anna Maria Ferrari,Cristina Leonelli,Cristina Siligardi and Gian CarloPellacani," MICROWAVE HYDROTHERMALSYNTHESISOF NANOCRYSTALLINEPOWDERS",Journal of American Ceramic Society,84[11]Page No:2728-2730(2001).
10. G.Dell Agli and G.Mascolo,"HYDROTHERMAL SYNTHESIS OF ZrO_2-Y_2O_3 SOLID SOLUTIONS AT LOW TEMPERATURE",Journal of the European Ceramic Society 20(2000) ,Page No:139-145.
11. Oleg Vasylkiv and Yoshio Sakka,"HYDROXIDE SYNTHESIS,COLLOIDAL PROCESSING AND SINTERING OF NAO-SIZE 3Y-TZP POWDER",Scripta Materialia,44(2001),Page No:2219-2223.

12. Y.B.Khollam,A.S.Deshpande,A.J.Patil ,H.S.Potdar,S.B.Deshpande,S.K.Date," SYNTHESIS OF YTTRIA STABILIZED CUBIC ZIRCONIA(YSZ)POWDERS BY MICROWAVE-HYDROTHERMAL ROUTE",Materials Chemistry and Physics 71(2001),Page No:235-241.
13. Kazuyoshi Sato,Kazuya Horiguchi,Taku Nishikawa,Sadahiro Yagishita,Kazuo Kuruma,Takeshi Murakami and Hiroya Abe,"HYDROTHERMAL SYNTHESIS OF YTTRIA-STABILIZED ZIRCONIA NANOCRYSTALS WITH CONTROLLED YTTRIA CONTENT",Inorganic Chemistry,Journal of American Chemical Society,(2015),Page No:1-8.
14. K.G.Kanade,J.O.Baeg,S.K.Apte,T.L.Praksh,B.B.Kale,"SYNTHESISAND CHARACTERIZATION OF NANO-CRYSTALLINED ZIRCONIA BY HYDROTHERMAL METHOD",Materials Research Bulletin 43(2008),Page No:723-729.
15. Christopher.J.Szepesi and James.H.Adair,"HIGH YIELD HYDROTHERMAL SYNTHESIS OF NAO-SCALE ZIRCONIA AND YTZP",Journal of American Ceramic Society 94[12](2011),Page No:4239-4246.
16. S.V.Chavan,K.T.Pillai and A.K.Tyagi,"COMBUSTION SYNTHESIS OF NANOCRYSTALLINE YTTRIA:TAILORING OF POWDER PROPERTIES",Materials Science & Engineering B132(2006),Page No:266-271.
17. R.D.Purohit,"COMBUSTION SYNTHESIS OF NANOCRYSTALLINE ZrO_2 POWDER:XRD,RAMAN SPECTROSCOPY AND TEM STUDIES",Materials Science & Engineering B 130(2006),Page No:57-60.
18. V.Grover,S.V.Chavan,P.U.Sasatry and A.K.Tyagi,"COMBUSTION SYNTHESIS OF NANOCRYSTALLINE $Zr_{0.80}Ce_{0.20}O_2$:DETAILED INVESTIGATIONS OF THE POWDER PROPERTIES",Journal of Alloys and Compounds 457(2008),Page No:498-505.
19. Zile Hua,Xin.M.Wang,Ping Xiao and Jianlin Shi,"SOLVENT EFFECT ON MICROSTRUCTURE OF YTTRIA – STABILIZED ZIRCONIA(YSZ) PARTICLES IN SOLVOTHERMAL SYNTHESIS",Journal of the European Ceramic Society 26(2006),Page No:2257-2264.
20. Xin.M.Wang,Gordon Lorimer and Ping Xiao,"SOLVOTHERMAL SYNTHESIS AND PROCESSING OF YTTRIA-STABILIZED ZIRCONIA NANOPOWDER",Journal of American Ceramic Society 88[4](2005),Page No:809-816.

21. Fawzy.G.Sherif and Lieh-Jiun Shyu,"EMULSION PRECIPITATION OF YTTRIA-STABILIZED ZIRCONIA FOR PLASMA SPRAY COATINGS",Journal of American Ceramic Society 74[2](1991),Page No:375-380.
22. Zhenwei Wang , Rob Hui , Nikica Bogdanovic , Zhaolin Tang, Sing Yick, Yongsong Xie , Igor Yaroslavski , Alan Burgess, Radenka Maric , Dave Ghosh,"PLASMA SPRAY SYNTHESIS OF ULTRA-FINE YSZ POWDER",Journal of Power Sources 170(2007),Page No:145-149.
23. S.T. Aruna, N. Balaji, K.S. Rajam,"PHASE TRANSFORMATION AND WEAR STUDIES OF PLASMA SPRAYED YTTRIA STABILIZED ZIRCONIA COATINGS CONTAINING VARIOUS mol% OF YTTRIA",Materials Characterization 62 (2 011) Page No:697 – 705.
24. Liu.D.Lord,O.T& Flewitt,P.E.J,"CALIBRATION OF RAMAN SPECTROSCOPY IN THE STRESS MEASUREMENT OF AIR-PLASMA-SPRAYED YTTRIA-STABILIZED ZIRCONIA",Applied Spectroscopy,66(10)(2012),Page No:1204-1209.
25. Mohammad RezaLoghman-Estarki, HosseinEdris, R.Shojarazavi, HosseinJamali, Reza Ghasemi, MousaPourbafrany, MohammadErfanmanesh, MazaherRamezani," SPRAY DRYING OF NANOMETRIC SYSZ POWDERS TO OBTAIN PLASMA SPRAYABLE NANOSTRUCTURED GRANULES" Ceramics International39(2013),Page No:9447–9457.
26. Mohammad RezaLoghman-Estarkia, MousaPourbafrany, RezaShojaRazavi, HosseinEdris, Saeed RezaBakhshi, MohammadErfanmanesh, HosseinJamali, SeyedNaveedHosseini, Morteza Hajizadeh-Oghaz," PREPARATION OF NANOSTRUCTURED YSZ GRANULES BY THE SPRAY DRYING METHOD" Ceramics International40(2014)Page No:3721–3729.
27. Seiichiro li,Hidehiro Yoshida, Koji Matsul,Nobukatsu Ohmichi and Yuicchi Ikhuhara," MICROSTUCTURE AND SURFACE SEGREGATION OF 3MOL% Y_2O_3 DOPED ZRO_2 PARTICLES",Journal of American Ceramic Society89[9],Page No:2952-2955(2006).
28. Guangsheng Pang,Elenna Sominska,Helmut Colfen,Yitzhak Mastai,Sigalit Avivi,Yuri Koltypin and Aharon Gedanken,"PREPARING A STABLE COLLOIDAL SOLUTION OF HYDROUS YSZ BY SONICATON",Journal of American Chemical

Society,Langmuir(2001),17,Page No:3223-3226.

29. Z.X.Yuan,J.Vleugels,o.VanDierBiest," PREPARATION OF Y_2O_3-COATED ZrO_2 POWDER BY SUSPENSION DRYING",Journal Of Materials Science Letters 19(2000),Page No:359-361.
30. Lionel Combemale,Gilles Caboche,Didier Stuerga,Denis Chaumont,"MICROWAVE SYNTHESIS OF YTTRIA STABILIZED ZIRCONIA",Materials Research Bulletin 40(2005),Page No:529-536
31. Chih-Wei Kuo, Yun-Hwei Shen, Shaw-Bing Wen, Huey-Er Lee, I.-Ming Hung,Hong-Hsin Huang, Moo-Chin Wang," PHASE TRANSFORMATION KINETICS OF 3 MOL% YTTRIA PARTIALLY STABILIZED ZIRCONIA (3Y-PSZ) NANOPOWDERS PREPARED BY A NON-ISOTHERMAL PROCESS", Ceramics International 37 (2011) Page No:341–347.
32. Chih-Wei Kuo, Yun-HweiShen, Feng-LinYen, Huy-ZuCheng, I-MingHung, Shaw-Bing Wen, Moo-ChinWang, MargaretStack," PHASE TRANSFORMATION BEHAVIOR OF 3mol% YTTRIA PARTIALLY-STABILIZED ZrO_2 (3Y–PSZ) PRECURSOR POWDER BY AN ISOTHERMAL METHOD", Ceramics International40(2014)Page No:3243–3251.
33. Ronald.C.Gravie,"THE OCCURRENCE OF METASTABLE ZIRCONIA AS A CRYSTALLITE SIZE EFFECT",Journal of physical chemistry,69[4],Page No:1238-1243(1965).
34. H.G.Scott,"PHASE RELATIONSHIPS IN THE ZIRCONIA-YTTRIA SYSTEM",Journal of Materials Science 10(1975),Page No:1527-1535.
35. Mary Sue Kaliszewski* and Arthur H. Heuer," ALCOHOL INTERACTION WITH ZIRCONIA POWDERS", Journal of American Ceramic Society 73 161, (1990),Page No:1504-1509.
36. P.D.L.Mercera,J.G.Van Ommen,E.B.M.Doesburg."INFLUENCE OF ETHANOL WASHING OF THE HYDROUS PRECURSOR ON THE TEXTURAL AND STRUCTURAL PROPERTIES OF ZIRCONIA",Journal of Materials Science 27,Page No:4890-4898(1992)
37. D.J.Chen and M.J.Mayo,"DENSIFICATION AND GRAIN GROWTH OF ULTRAFINE 3MOL%Y_2O_3-ZrO_2 CERAMICS",Nanostructured Materials,2,Page No:469-478(1993).
38. Mariana Lauci,"POWDERS AGGLOMERATION GRADE IN THE ZrO_2-Y_2O_3 CO-PRECIPITATION PROCESS",Key Engineering Materials Volumes,132-136(1997),Page No:89-92.

39. C.D.Sagel-Ransjin,A.J.A.Winnubst,A.J.Burggraaf and H.Verweij,"THE INFLUENCE OF CRYSTALLIZATION AND WASHING MEDIUM ON THE CHARACTERISTICS OF NANOCRYSTALLINE Y-TZP",Journal of European Ceramic Society16,Page No:759-766(1996).
40. W.Z.Zhu and M.Yan,"EFFECT OF GRAIN SIZE ON THE KINETICS OF ISOTHERMAL TETRAGONAL TO MONOCLINIC TRANSFORMATION IN ZrO_2(2MOL% Y_2O_3)CERAMICS",Journal of European Ceramic Society 17,Page No:1729-1739(1997).
41. P. Duran,J. Tartaj,J.F. Fernandez,M. Villegas,C. Moure," CRYSTALLISATION AND SINTERING BEHAVIOUR OF NANOCRYSTALLINE Y-TZP POWDERS OBTAINED BY SEEDING-ASSISTED CHEMICAL COPRECIPITATION", Ceramics International 25 (1999) ,Page No:125-135.
42. O.Vasylkiv and Y.Sakka, ''SYNTHESIS AND COLLOIDAL PROCESSING OF ZIRCONIA NANOPOWDER,'' Journal of American Ceramic Society, 84(2001),Page No: 2489–94.
43. Shaoyan Wang and Yuchun Zhai,Xiaoan Li,Yang Li and Kiaming Wang,"COPRECIPITATION SYNTHESIS OF MgO-DOPED ZrO_2 NANOPOWDER",Journal of American Ceramic Society 89[11],Page No:3577-3581.
44. Erika Furlani, Eleonora Aneggi, Stefano Maschio," EFFECTS OF MILLING ON CO-PRECIPITATED 3Y-PSZ POWDERS", Journal of the European Ceramic Society 29 (2009) ,Page No:1641–1645.
45. Yu-Wei Hsu, Ko-Ho Yang, Kuo-Ming Chang, Sung-Wei Yeh, Moo-Chin Wang," SYNTHESIS AND CRYSTALLIZATION BEHAVIOR OF 3 MOL% YTTRIA STABILIZED TETRAGONAL ZIRCONIA POLYCRYSTALS (3Y-TZP) NANOSIZED POWDERS PREPARED USING A SIMPLE CO-PRECIPITATION PROCESS", Journal of Alloys and Compounds 509 (2011) Page No:6864–6870.
46. Sharanabasappa B. Patil, Ajay Kumar Jena, and Parag Bhargava," INFLUENCE OF ETHANOL AMOUNT DURING WASHING ON DEAGGLOMERATION OF CO-PRECIPITATED CALCINED NANOCRYSTALLINE 3YSZ POWDERS", International Journal Applied Ceramic Technology(2012),Page No: 1–11.
47. Hung-Jui Huang, Moo-Chin Wang," THE PHASE FORMATION AND STABILITY OF TETRAGONAL ZrO_2 PREPARED IN A SILICA

BATH", Ceramics International 39 (2013) ,Page No:1729–1739.

48. Chau-Hsiang Wang,Moo-ChinWang,Je-KangDu, Yu-YouSie, Chi-Shiung Hsi, Huey-ErLee, "PHASE TRANSFORMATION AND NANOCRYSTALLITE GROWTH BEHAVIOR OF 2 MOL% YTTRIA-PARTIALLY STABILIZED ZIRCONIA (2Y-PSZ) POWDERS", Ceramics International 39 (2013),Page No:5165–5174.
49. Ajay Kumar Pandey and Koushik Biswas,"EFFECT OF AGGLOMERATION AND CALCINATION TEMPERATURE ON THE MECHANICAL PROPERTIES OF YTTRIA STABILIZED ZIRCONIA(YSZ)",Ceramics International (2014),PageNo:1-7.
50. Cheng-Li Wang , Weng-Sing Hwang , Hsueh-Liang Chu,Feng-Lin Yen ,Chi-Yuen Hwang ,Chi-Shiung Hsi ,Huey-Er Lee , Moo-Chin Wang," PHASE TRANSFORMATION AND CRYSTALLINE GROWTH OF 4 mol% YTTRIA PARTIALLY STABILIZED ZIRCONIA", Journal of Sol-Gel Science Technology (2014) 70:Page No:428–440.
51. Thomaz Kosmac,Rudolf Wagner and Nils Claussen,"X-RAY DETERMINATION OF TRANSFORMATION DEPTHS IN CERAMICS CONTAINING TETRAGONAL ZrO_2",Communications of the American Ceramic Society,(1981),C-72.
52. E.Dow.Whitney,"KINETICS AND MECHANISM OF THE TRANSITION OF METASTABLE TETRAGONAL TO MONOCLINIC ZIRCONIA",Page No:1999-2000(1965).
53. T.K. Gupta,J.H.Bechtold,R.C.Kuznicki,L.H. Cadoff,B.R.Rossing, "STABILIZATION OF TETRAGONAL PHASE IN POLYCRYSTALLINE ZIRCONIA",Journalof MaterialsScience,12(1971),Page No:2421–2426.
54. F.F.Lange,"TRANSFORMATION TOUGHENEING,PART-3 EXPERIMENTAL OBSERVATIONS IN THE ZrO_2-Y_2O_3 SYSTEM",Journal of Materials Science 17(1982),Page No:240-246.
55. T. Sato,M.Shimada,"CONTROL OF THE TETRAGONAL-TO-MONOCLINIC PHASE TRANSFORMATION OF YTTRIA PARTIALLY STABILIZED ZIRCONIA IN HOTWATER",Journal of Materials Science,20(1985),Page No:3988–3992.
56. A.H.Heuer,"TRANSFORMATION TOUGHENING IN ZrO_2-CONTAINING CERAMICS",Journal of The American Ceramic

Society,Volume 70,No 10(1987),Page No:689-698.

57. P.Christel,A.Meunier,M.Heller,J.P.Torre and C.N.Pielle,"MECHANICAL PROPERTIES AND SHORT-TERM IN –VIVO EVALUATION OF YTTRIUM-OXIDE-PARTIALLY-STABILIZED ZIRCONIA,"Journal of Biomedical Materials Research,Volume 23(1989),Page No:45-61.
58. W.Z. Zhu,M.Yan,"EFFECT OF GRAIN SIZE ON THE KINETICS OF ISOTHERMAL TETRAGONAL TO MONOCLINIC TRANSFORMATION IN ZrO_2 (2 mol%Y_2O_3) CERAMICS", JournaloftheEuropeanCeramicSociety, 17(1997),Page No:1729–1739
59. Sigrid Benfer and Erich Knozinger,"STRUCTURE,MORPHOLOGY AND SURFACE PROPERTIES OF NANOSTRUCTURED ZrO_2 PARTICLES",Journal of Materials Chemistry 9(1991),Page No:1203-1209.
60. Richard H.J.Hannik,Patrick.M.Kelly and Barry.C.Muddle,"TRANSFORMATION TOUGHENING IN ZIRCONIA-CONTAINING CERAMICS",Journal of American Ceramic Society 83[3],Page No:461-487(2000).
61. Alfonso Bravo-Leo,Yuichiro Morikava,Masanori Kawahara,Merrilea.J.Mayo,"FRACTURE TOUGHNESS OF CYSTALLINE TETRAGONAL ZIRCONIA WITH LOW YTTRIA CONTENT",Acta Materialia 50,Page No:4555-4562(2002).
62. J.Robert Kelly and Isabelle Denry,"STABILIZED ZIRCONIA AS A STRUCTURAL CERAMIC:AN OVERVIEW",Dental Materials 24(2008),Page No:289-298.
63. Dolores R.R. Lazar , Marco C. Bottino, Mutlu O zcan, Luiz Felipe Valandro, Regina Amaral , Valter Ussui, Ana H.A. Bressiani," Y-TZP CERAMIC PROCESSING FROM COPRECIPITATED POWDERS: A COMPARATIVE STUDY WITH THREE COMMERCIAL DENTAL CERAMICS", Dental Materials 24 (2008)Page No: 1676–1685.
64. Georg Garnweiter,"ZIRCONIA NANOMATERIALS:SYNTHESIS AND BIOMEDICAL APPLICATION",Nanomaterials for the Life Sciences,Volume 2(2009),Page No:245-285.
65. Aleksej Zarkov,Andrius Stanulis,Jolita Sakaliuniene,Skirmante Butkute,Brigita Abakeviciene,Tomas Salkus, Stasys Tautkus,Antanas F. Orliukas,Sigitas Tamulevicius,Aivaras Kareiva,"ON THE SYNTHESIS OF YTTRIA-STABILIZED ZIRCONIA: A COMPARATIVE STUDY", Journal of Sol-Gel Science Technology (2015) 76:Page No:309–319.

66. M.Pourbafrani,R.Shoja Razavi,S.R.Bakhshi,M.R.Loghman-Estarki and H.Jamali,"EFFECT OF MICROSTRUCTURE AND PHASE OF NANOSTRUCTURED YSZ THERMAL BARRIER COATINGS ON ITS THEMAL SHOCK BEHAVIOUR",Surface Engineering,Volume 31(2014),Page No:64-73.
67. Satish Tailor,Manoj Singh and A.V.Doub,"SYNTHESIS AND CHARACTERIZATION OF YTTRIA-STABILIZED ZIRCONIA(YSZ) NANO-CLUSTERS FOR THERAML BARRIER COATINGS(TBCs) APPLICATIONS",Journal of Cluster Science(2016),Page No:1-12.
68. R.Vaben,D.Stover,"INFLUENCE OF MICROSTRUCTURE ON THE THERMAL CYCLING PERFORMNCE OF THERMAL BARRIER COATINGS",Page No:1-6.
69. Vladimir V. Srdic, Markus Winterer, and Horst Hahn,"SINTERING BEHAVIOR OF NANOCRYSTALLINE ZIRCONIA PREPARED BY CHEMICAL VAPOR SYNTHESIS",Journal of American Ceramic Society, 83 [4] (2000),Page No:729–736.
70. Sharanabasappa B. Patil, Parag Bhargava," CHARACTERIZATION OF AGGLOMERATION STATE IN NANOCRYSTALLINE 3YSZ POWDERS THROUGH PRESSURE–DISPLACEMENT CURVES AND NANOINDENTATION OF GREEN COMPACTS" Powder Technology 228 (2012), Page No: 272–276.
71. Seiichiro li,Hidehiro Yoshida,Koji Matsui,Nobukatsu Ohmichi and Yuichi Ikuhara,"MICROSTRUCTURE AND SURFACE SEGREGATION OF 3mol% Y_2O_3-DOPED ZrO_2 PARTICLES",Journal of American Ceramic Society 89[9](2006),Page No:2952-2955.
72. Xianshuang Xin , Zhe Lu, Xiqiang Huang , Xueqing Sha ,Yaohui Zhang , Wenhui Su," INFLUENCE OF SYNTHESIS ROUTES ON THE PERFORMANCE FROM WEAKLY AGGLOMERATED YTTRIA-STABILIZED ZIRCONIA NANOMATERIALS", Materials Research Bulletin 41 (2006) Page No:1319–1329.
73. Alian Methivier and Michele Pijolat,"THERMAL STABILITY OF ZIRCONIA AS A CATALYST SUPPORT:KINETICS AND MODELLING",Journal of Catalysis 139(1993),Page No:329-337.
74. Hongliang Zhu, Deren Yang, Zhenqiang Xi,and Luming Zhu." HYDROTHERMAL SYNTHESIS AND CHARACTERIZATION OF ZIRCONIA NANOCRYSTALLITES", Journal of American Ceramic Society, 90 [4] (2007),Page No:1334–1338.

75. R. Mueller, R. Jossen, S. E. Pratsinis, M. Watson, and M. K. Akhtar, ‘‘ZIRCONIA NANOPARTICLES MADE IN SPRAY FLAMES AT HIGH PRODUCTION RATES,’’ Journal of American Ceramic Society, 87(2004),Page No:197–202 .
76. C. Piconi and G. Maccauro, ‘‘ZIRCONIA AS A CERAMIC BIOMATERIAL,’’ Biomaterials, 20, (1991)Page No:1–25.
77. W. C. Maskell, ‘‘PROGRESS IN THE DEVELOPMENT OF ZIRCONIA GAS SENSORS,’’ Solid State Ionics, 134(2000),Page No: 43–50.
78. I. W. Chen and L. A. Xue, ‘‘DEVELOPMENT OF SUPERPLASTIC STRUCTURAL CERAMICS,’’ Journal of American Ceramic Society, 73(1990), Page No:2585–2609.
79. N. Igawa and Y. Ishii, ‘‘CRYSTAL STRUCTURE OF METASTABLE TETRAGONAL ZIRCONIA UP TO 1472 K,’’ Journal of American Ceramic Society, 84(2001), Page No:1169–1171.
80. A. Bravo-Leon, Y. Morikawa, M. Kawahara, and M. J. Mayo, ‘‘FRACTURE TOUGHNESS OF NANOCRYSTALLINE TETRAGONAL ZIRCONIA WITH LOW YTTRIA CONTENT,’’ Acta Materials,50(2002), Page No:4555–4562.
81. M. A. Meyers, A. Mishra, and D. J. Benson, ‘‘MECHANICAL PROPERTIES OF NANOCRYSTALLINE MATERIALS,’’ Progress in Material Science, 51(2006),Page No: 427–556.
82. J. C. Ray, A. B. Panda, C. R. Saha, and P. Pramanik, ‘‘SYNTHESIS OF NIOBIUM(V)- STABILIZED TETRAGONAL ZIRCONIA NANOCRYSTALLINE POWDERS,’’ Journal of American Ceramic Society, 86(2003), Page No:514–516.
83. J. C. Ray, P. Pramanik, and S. Ram, ‘‘A NOVEL POLYMER MATRIX METHOD FORSYNTHESIZING ZrO_2 NANOCRYSTALS AT MODERATE TEMPERATURE,’’Journal of MaterialScience Letters,20(2001),Page No: 2017–2019.
84. M. Yashima, K. Ohtake, M. Kakihana, and M.Yoshimura, ‘‘SYNTHESIS OF METASTABLE TETRAGONAL (TO) ZIRCONIA–CERIA SOLID SOLUTIONS BY THE POLYMERIZED COMPLEX METHOD,’’ Journal of American Ceramic Society, 77(1994), Page No: 2773–2776.
85. D.-J. Chen and M. J. Mayo, “DENSIFICATION AND GRAIN GROWTH OF ULTRAFINE 3mol% Y_2O_3–ZrO_2 CERAMICS,” Nanostructured Materials, 2(1993), Page No:469–478.
86. F. Frey, H. Boysen, and T. Vogt, “NEUTRON POWDER INVESTIGATION OF THE

MONOCLINIC TO TETRAGONAL PHASE TRANSFORMATION IN UNDOPED ZIRCONIA," Acta Crystallo, B46(1990),Page No:724–730.

87. W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, Introduction to Ceramics ,Wiley, New York, 1976.
88. M. J. Mayo and D. C. Hague, "POROSITY-GRAIN GROWTH RELATIONSHIPS IN THE SINTERING OF NANOCRYSTALLINE CERAMICS," Nanostruct. Mater., 3 [1–6] (1993),Page No:43–52
89. P. L. Chen and I-W. Chen, "SINTERING OF FINE OXIDE POWDERS: I, MICROSTRUCTURAL EVOLUTION," Journal of American Ceramic Society, 79 [12] (1996).Page No:3129–3141.
90. I-W. Chen, "MOBILITY CONTROL OF CERAMIC GRAIN BOUNDARIES AND INTERFACES,"Material Science and Engineering, A166(1993),Page No:51–58.
91. A. J. Allen, S. Krueger, G. Skandan, G. G. Long, H. Hahn, H. M. Kerch, J. C.Parker, and M. N. Ali, "MICROSTRUCTURAL EVOLUTION DURING THE SINTERING OF NANOSTRUCTURED CERAMICS OXIDES," Journal of American Ceramic Society, 79 [5] (1996),Page No:1201–1212.
92. M.J. Readey, R.R. Lee, J.W. Halloran, Arthur H. Heuer,"PROCESSING AND SINTERING OFULTRAFINE $MgO\text{-}ZrO_2$ AND $[MgO\text{-}Y_2O_3]\text{-}ZrO_2$POWDERS", Journal of the American CeramicSociety 73 (6) (1990) ,Page No:1499–1503.
93. Jia-Lin Shi, Jian-Hua Gao, Zu-Xiang, Tung-Sheng Yen,"SINTERING BEHAVIOR OF FULLY AGGLOMERATED ZIRCONIA COMPACTS, Journal of the American Ceramic Society 74 (5) (1991),Page No:994–997.
94. J.L. Shi, Z.X. Lin, W.J. Qian, T.S. Yen, "CHARACTERIZATION OF AGGLOMERATION STRENGTH OF COPRECIPITATED SUPERFINE ZIRCONIA POWDERS", Journal of the European Ceramic Society13 (1994),Page No:265–271.
95. Jerome Chevalier, Laurent Gremillard, "THE TETRAGONAL-MONOCLINIC TRANSFORMATION IN ZIRCONIA: LESSONS LEARNED AND FUTURE TRENDS", Journal of the American CeramicSociety 92 (9) (2009),Page No:1901–1920.
96. C. Pascual,P.Duran,"SUB SOLIDUS PHASE EQUILIBRIA AND ORDERING IN THE SYSTEM ZrO_2–Y_2O_3", Journal of the American Ceramic Society,66(1983),Page No: 23–27.

97. .C.H. Wang, M.C.Wang ,J.K.Du ,Y.Y.Sie, C.S.Hsi ,H.E.Lee, ”PHASE TRANSFORMATION AND NANOCRYSTALLITE GROWTH BEHAVIOR OF 2mol% YTTRIA PARTIALLY STABILIZED ZIRCONIA (2Y–PSZ) POWDERS,CeramicsInternational, 39 (2013),Page No:5165–5174.
98. E.S. Machlin, M.Cohen,” BURST PHENOMENON IN THE MARTENSITIC TRANSFORMATION”, Transactions of AIME ,191(1951),Page No:746–754.
99. E.C.Subbaro,H.S.Maiti,K.K.Srivastava , ”MARTENSITIC TRANSFORMATION IN ZIRCONIA”, Physics status solidia:AppliedResearch,21(1974),Page No:9–40.
100. D.J. Kim, H.J.Huang ,D.H.Cho, “PHASE TRANSFORMATIONS OF Y_2O_3 AND Nb_2O_5 DOPED TETRAGONAL ZIRCONIA DURING LOW TEMPERATURE AGING IN AIR”, Solid StateIonics,80(1985),Page No:67–75.
101. X.Q. Cao,R.Vassen,S.Schwartz,W.Jungen,F .Tietz,D.Stöever, “SPRAY-DRYING OF CERAMICS FOR PLASMA-SPRAY COATING”,Journal of European Ceramic Society,20 (2000),Page No: 2433–2439.
102. R.H.Piva, D.H.Piva, J.J.Pierri, O.R.K.Montedo, M.R.Morelli, “AZEOTROPIC DISTILLATION,ETHANOL WASHING,AND FREEZE DRYING ON COPRECIPITATED GELS FOR PRODUCTION OF HIGH SURFACE 3Y-TZP AND 8YSZ POWDERS:A COMPARATIVE STUDY”,Ceramics International,Page No:1-9(2015).
103. AntonioDiaz-Parralejo, Antonio Macias-Garcia, Angel L.Ortiz ,Eduardo,M.Cuerda-Correa, “EFFECT OF CALCINATIONS TEMPERATURE ON THE TEXTURAL PROPERTIES OF 3MOL% YTTRIA-STABILIZED ZIRCONIA POWDERS”,Journal of Non-Crystalline Solids 356(2010),Page No:175-178.
104. https://en.wikipedia.org/wiki/1-Propanol
105. https://pubchem.ncbi.nlm.nih.gov/compound/1-propanol#section=LogP
106. https://en.wikipedia.org/wiki/1-Propanol#/media/File:Propanol_reactions.png