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Review of Ceramic Materials and Recent Development of Preparation Methods

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Abstract

Ceramics globally has been developed by various materials and methods to find suitable ceramics for specific applications. This paper discusses the development of several methods in ceramic preparation such as hot-pressing, sintering, co-precipitation, and solid-state method. In 2001 up to 2019, the hot-pressing method was used to manufacture ceramic B4C and SiAlCO as raw material doping by (W, Ti)C. In 2002 up to 2018 sintering method by using fly ash as raw material with an additional K2CO3, Na2CO3, and Nb2O5. In 2008, the co-precipitation method was used for CaCu3Ti4O12 (CCTO) as raw material until 2019, and then the ZrO2-Al2O3 as a newcomer ceramic material. From 2001 up to 2017, the solid-state method was used with microwave for MgTiO and 3-CaTiO with Eu and (Lu, Gd) 2O3 as a dopant. This paper provided the four methods and the materials from reported references from 2000 up to now, as guidance in producing the specific functional ceramics in the future.

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1. INTRODUCTION

Ceramics in the Greek word called “Keramicos” means combustible material. Ceramics are generally inorganic and non-metallic solids (made from powder materials), which have relatively high melting point properties and require high temperatures for manufactureand applicationn. Ceramic-forming compounds and elements usually consist of several different compounds and elements or a combination of compounds, between metals and non-metals elements (mainly O, B, C, N), which can be oxides, carbides, borides, silicides. Their bonds are either ionic or a combination of covalent and ionic. For thousands of centuries ago, ceramics were known and made from natural raw materials. Ceramics present a broad range of attractive properties including thermal insulation, lightweight, high specific surface area, and thermal shock resistance compared to other materials. Ceramics do not deform at long operating cycles, have more economical maintenance costs, and have excellent quality stability in a wide range of organic solvents [1].

Along with the times, the demand for ceramic materials is increasing with more diverse materials and wider applications in the biomedical, building materials, electronics, and environmental fields. Some ceramic materials and fabrication methods have been widely developed with a more specialized nature of the task. Material, fabrication methods, and processing methods drive the characteristics of a ceramic including corrosion resistance, mechanical strength, density, and outstanding optical and electrical properties. various materials for the preparation of ceramic manufacture, the fabrication methods, and components of ceramic composites were investigated to demonstrate the contribution of various materials and fabrication methods in identifying the properties of a ceramic component [2].

2. FABRICATION METHOD OF CERAMICS

The manufacture of ceramics is carried out using the method as the origin Mechanical, structural, and physical properties such as compressive strength, crystalline phase, density, porosity, and linear expansion of ceramics [3]. Ceramic fabrication can be achieved through several methods and materials for making ceramics are shown in Table 1.

2.1 Preparation of Hot pressing

In the feng wang research, composite (Ti,Mo)Al/Al_2O_3 was successfully synthesized by hot pressing based on the Ti–Al–TiO_2–MoO_3 system where in-situ hot pressing utilizes low energy requirement, contaminant-free and stable interface and chemistry, which can overcome this weakness TiAl based alloys and improve in-service properties of the TiAl composite [70]. Figure 1 shows a schematic illustration hot pressing process for glass-ceramics.

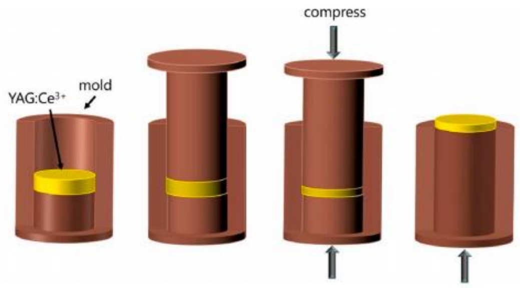

Figure 1. Schematic illustration of hot pressing sintering mold and sintering process [71].

Manufacturing by hot press or melt grow methods will usually produce ceramics with high strength and strong yielding strength [5]. In the 2020s, Shu-Rong Yan et al.l made publications on the pressing method effects of SiC amount and morphology on the properties of TiB_2-based composites sintered by hot-pressing. Relative density studies reveal that some peaks associated with graphite carbon also appear in the SiCw-doped ceramic pattern. However, The XRD investigation confirmed the production of an in-situ TiC phase during the hot-pressing [72].

Table 1. Ceramic materials, particle size, purity, and fabrication method

Ceramic materials	Particle size	Purity (%)	Fabrication Methods	Ref
B4C	3–5 mm	>95	Hot pressing	[4]
(W, Ti) C.	1–2 mm	>99		
$Al_2O_3/Er_3Al5O_{12}/ZrO_2$		99.9	Hot pressing	[5]
Zirconia / veneering ceramic composites.			Metal-ceramic technique	[6]
Al_2O_3-YAG: Ce			High-power laser lighting	[7]
Ceramic zirconia, alumina, and silicon nitride			Single edge V-notched beam (SEVNB) method	[8]
TiO_2			Sintered through microwave and conventional processes	[9]
K_2CO_3, Na2CO3, and Nb_2O_5		99,95	Conventional powder synthesis	[10]
Clay-based material			Electrophoretic deposition (EPD)	[11]
Electric arc furnace dust Powder EAFD			Two-stage heat treatment	[12]
SiO_2, Na_2CO_3, and $CaCO_3$				
$CaCO_3$, TiO_2 (Aldrich), Ta_2O_5, and Nb_2O_5 (NFC)		> 99	Conventional solid-state ceramic route	[13]
MgTiO sintering 3–CaTiO			Solid-state method	[14]
Neodymium doped yttrium aluminum garnet (Y Al O) nanocrystalline			Solid-state laser nanocrystalline fabrication process	[15]
Ca_2SiO_4			Archimedes' method, technic indentation Vickers	[16]
Aluminum-magnesium hydrocarbon			Hydrolysis (Mg6Al2(CO3)(OH)16Á4H2O)	[17]
Fly ash	0,2 - 500 mm		Powder sintering technology	[18]
Niobate(M_2+Nb_2O_6)		-		[19]
oksida rute		99,9		
Alumina ceramics			Abrasive jet machining (AJM), micro-machining method	[20]
Zirkonia				[21]
Ceramics $Ba_2Zn_1xCaxWO_6$			Solid-state reaction	[22]
Hyperbranched alkyd / γ-Al_2O_3 nanorods composite c	20 nm		Hydrothermal and decomposition methods	[23]
Methyltriacetoxysilane		95	Nanoindentation test method and the new substrate independent nanoindentation test method.	[24]
Methyltrimethoxysilane		98		
tetramethoxysi		97		
Magnesium ZK_{10}				[25]
TiO_2			Spray and flow coating method	[26]
Terbium gallium garnet (TGG)	158 nm		Co-precipitation method and sintering method.	[27]
Fly ash, window waste glass, and fluorite (CaF_2)	75µm			[28]

Ceramic materials	Particle size	Purity (%)	Fabrication Methods	Ref
Eu, doping $(Lu, Gd)_2O_3$			The solid-state reaction method combined with vacuum sintering without sintering aids	[29]
Cerium doped lutetium aluminum garnet single crystal			Sintering in an oxygen atmosphere and post hot isostatic pressing	[30]
$Lu (NO_3)_3$ and $Eu (NO_3)_3$	68 nm		Co-precipitation method	[31]
CNTs and Al_2O_3 powders	10 and 5 mm,		Sintering method	[32]
Nanocomposite PEO-LiX				[33]
Al_2O_3 TiC	(0,5 mm) and (0,8 mm)		Machining methods(electro-discharge machining (EDM), ultrasonic machining (USM)	[34]
Fe_2O_3/ TiO_2			Co-precipitation method	[35]
Bio-amorphous SiOC/C-ceramic composites				[36]
Sialon – Si_3N_4 graded nano-			Hot-pressing, pin-on-disk method	[37]
Polydimethylsiloxane (PDMS) and Zeolit ZSM-5 (Si / A)	4,9 m		Dispersion method	[38]
Alumina and aluminum-magnesium alloys	9 mm		Gel casting	[39]
Zirconium diboride - zirconium carbide (ZrB_2 – ZrC), zirconium diboride-zirconium nitride (ZrB_2 -ZrN), zirconium diboride-silicon carbide (ZrB_2 -SiC), and zirconium diboride-aluminum nitride (ZrB_2 -AlN)			Hot pressing	[40]
Blast furnace slag			Method of preparing glass–ceramics that are processed directly through heat treatment	[41]
SiAlON	250 mm		powder bed, rapid cooling, and laminating.	[42]
MgO	diameter 12.7 mm, thick 1 mm		Hot-pressing	[43]
Multiphase ceramic waste		99,5	Melt processing	[44]
Bi_2O_3, Al_2O_3, $BaCO_3$, and TiO_2		99,	Solid-state reaction method and sol-gel method	[45]
$BaCO_3$, $CaCO_3$ TiO_2 and SnO_2		99.0, 99.0, 99,5, and 99,0	The conventional solid-state reaction method	[46]
$BiFeO_3$			Conventional solid-state-reaction and mechanical activation assisted solid-state-reaction method	[47]
Calcium titanate ($CaTiO_3$)	0.26 - 2.32 m		The conventional solid-state reaction method	[48]
Barium carbonate ($BaCO_3$), zirconium(IV) oxide (ZrO_2), and yttrium(III) oxide ($9Y_2O_3$)		99,8 99.7, 99.9,	Solid-state reactive sintering	[49]
Bi_2O_3, TiO_2, La_2O_3, Na_2CO_3, and $SrCO_3$	~ 10 mm and ~ 1 mm		Conventional solid-state reaction method.	[50]
$MgAl_2O_4$			Hot pressing	[51]
ZrB_2 and SiC	2 mm and 5 µm	99 and 99	Hot pressing	[52]

Table 1 continue…

Ceramic materials	Particle size	Purity (%)	Fabrication Methods	Ref
$MgAl_2O_4$	55 nm		Hot pressing	[53]
SiB0.5C1.5N0.5 powders	4–5 nm		Mechanical alloying and hot pressing	[54]
Cr Al	75 m 75 m	99 99,5	Hot-pressing technology	[55]
Ti_6Al_4V	45 µm		Hot-pressing	[56]
TiB_2–SiC	1-2 µm		Reactive hot pressing	[57]
HfB_2–SiC			Hot-pressing and spark plasma sintering	[58]
K_2CO_3, Na_2CO_3, and Nb_2O_5		99, 0 99,8 99, 99	Cold sintering assisted sintering	[59]
Bi_2O_3, Na_2CO_3, K_2CO_3, $BaCO_3$, TiO_2, and Nb_2O_5		>99.9	Two-step sintering method	[60]
Alumina	150 nm		Two-step sintering method	[61]
MgO, TiO_2, and CoO	diameter 10 mm and thick 5 mm	≥98, ≥99, and ≥99	Conventional sintering method	[62]
Y $(NO_3)_3$ $6H_2O$, Al $(NO_3)_3$ $9H_2O$		>99,9, >99,9	Co-precipitation synthesis and two-step sintering	[63]
ZrO_2–Al_2O_3			Co-precipitation method	[64]
Ni $(NO_3)_2$ .6H2O, Zn $(NO_3)_2$ $.6H_2O$, and Fe $(NO_3)_3$ $.9H_2O$		99,999	Co-precipitation method	[65]
$MnSO_4$ H_2O, copper sulfate $CuSO_{45}H_2O$, and nickel sulfate $NiSO_{46}H_2O$		99, 99 and 98,5	Co-precipitation and solid-state method	[66]
$CaCu_3Ti_4O_{12}$ (CCTO)			Co-precipitation method	[67]
Yttria (Y_2O_3), aluminum nitrate nonahydrate ($Al(NO_3)_3 \cdot 9H_2O$, ammonium hydrogen carbonate (NH_4HCO_3), and ammonium sulfate ($(NH_4)_2 \cdot SO_4$)		99.99, >98, >99	Co-precipitation method	[68]
Fly ash			Powder sintering technology	[69]

In 2020 Shunheng Wang and Juncheng Liu prepared ceramic using hot-pressing sintering and melt grow Sample by comparing $Al_2O_3/Er_3Al_5O_{12}/ZrO_2$ ceramics with eutectic composition divided into four sets, directionless solidified eutectic ceramics (N-DSEC), directionally solidified eutectic ceramics (DSEC), rapidly quenched eutectic ceramics (RQEC) and hot pressing sintered ceramics (HPSC). The results obtained from the relationship between microstructure and mechanical properties investigated showed that DSEC had the highest flexural strength of 721.8 Mpa, RQEC had the highest hardness of 17.3 GPa, and HPSC had the highest fracture toughness of 6.8 $MPa \cdot m^{1/2}$, an improvement from density, increased microuniformity and smaller defects in the sample will benefit the mechanical properties of the sample [73]. Figure 1 shows a schematic illustration of hot-pressing methods and the results from reported references were summarized in Table 2.

In 2001, Jianxin has conducted research with ceramic base materials from B4C with (W,Ti)C doping which explains the effect of (W,Ti)C content on the mechanical and micro properties of B_4C/(W,Ti)C ceramic composites with different solids. -Solution (W,Ti)C content produced by hot pressing method. The results show that a chemical reaction occurs for this system during hot pressing, and results in $B_4C/TiB_2/W2B_5$ composites with high density and better mechanical properties compared to monolithic B_4C ceramics. hardness decreased with increasing (W,Ti)C content, while fracture toughness and flexural strength continued to increase with increasing (W,Ti)C content up to 50 wt.% [4]. Figure 2 shows technological developments in ceramic using the hot-pressing method from the last few decades.

In 2010 S.B. Li et all used a hot pressing mechanism to synthesize Cr_2AlC ceramics. On the flexural strength, fracture toughness, and Vickers hardness of the fine-grained Cr_2AlC determined and compared with the values for the synthesized fine-grained Cr_2AlC has a high density of 99% which is higher than the coarse-grained Cr_2AlC (grain size is about 35µm) i.e. 95% synthesized by hot pressing of unground Cr, Al, and C [55].

Table 2. Classification of hot-pressing methods from the last few decades

Materials	Preparation Method	Years	Ref
B4C doping (W, Ti) C	Hot pressing techniques	2001	[4]
MgO	Hot-pressing	2003	[43]
ZrB2–ZrC , ZrB2 -ZrN, ZrB2 – SiC and ZrB2 -AlN	Hot-pressing	2004	[40]
HfB_2–SiC	Hot-pressing and spark plasma sintering	2006	[58]
SiB0.5C1.5N0.5 powders	Mechanical alloying and hot pressing	2007	[54]
Cr and Al	Hot-pressing technology	2010	[55]
Sialon – $Si3N_4$ graded nano	Hot-pressing, pin-on-disk method	2012	[37]
TiB_2–SiC	Reactive hot pressing	2013	[57]
ZrB_2 and SiC	Hot-pressing	2015	[52]
Ti_6Al_4V	Hot-pressing	2016	[56]
$MgAl_2O_4$	Hot-pressing	2017	[51]
$MgAl_2O_4$	Hot-pressing	2018	[53]
$Al_2O_3/Er_3Al_5O_{12}/ZrO_2$	Hot-pressing	2020	[5]

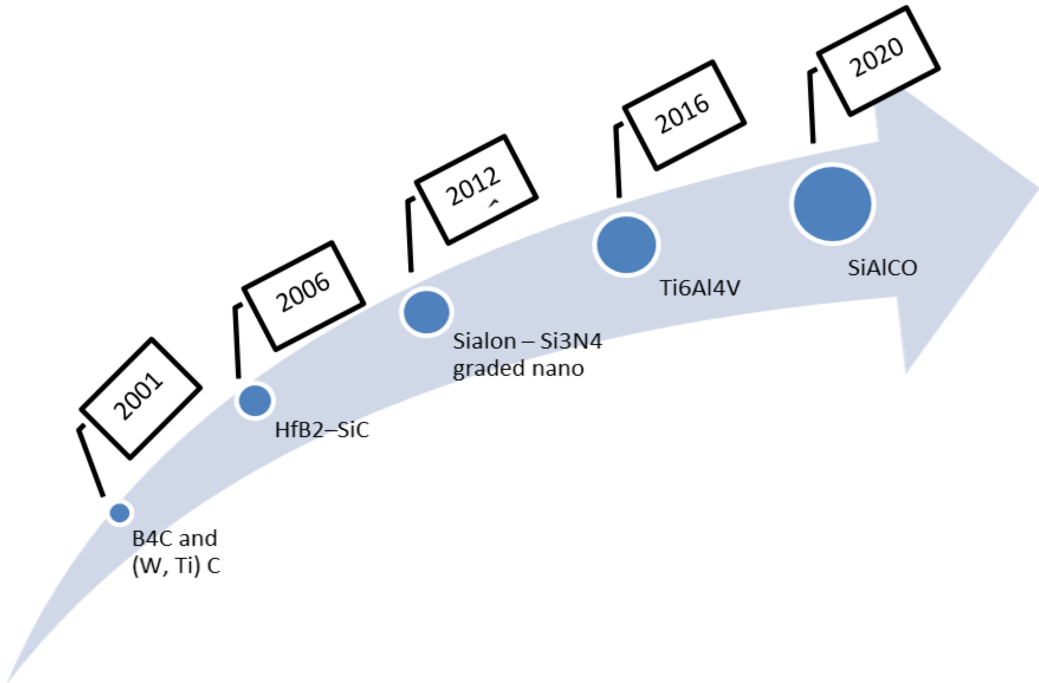

Figure 2. Technological developments use of hot-pressing method 2001-2020

2.2 Preparation of Sintering method

In simple terms, sintering can be described as the application of heat and pressure (see Table 3). Since the main focus of the sintering process is to achieve maximum compression, sintering parameters such as temperature, pressure, and retention time will change until this is achieved. As shown in Figure 3, great efforts have been made to develop a sintering process for the complete compaction of bulk composites. This is the technological development of the sintering process from 2002-to 2018 [74]. The development of the sintering method in recent years has been carried out thoroughly. This is for bulk nanocomposite densification because the pores in the material significantly affect the mechanical properties, reducing porosity thereby increasing the performance of nanocomposites [75].

In 2019, Xiaoyan Liu at all has conducted research preparation of alumina ceramics by sintering method with a zirconia structure (ZTA) has a high level of strength, high hardness, high toughness, and good thermal resistance which can be applied to implants and biomedical [76]. One of the scientific papers published by Shan-Shan at all in 2019 stated the effect of sintering temperature on microstructure, shrinkage, porosity, phase composition, mechanical properties, and pore size distribution of ceramics through selective laser sintering of poly-hollow microspheres (PHM) Al_2O_3. This method is capable of directly preparing ceramic foams with complex shapes and control properties of ceramic foams [77].

Researchers made effort to study the sintering behavior, phase composition and microwave dielectric properties of $BaAl_2{-}2x(ZnSi)xSi_2O_8$ ceramics. Aluminum content has an important influence on the sintering temperature, besides the sintering temperature, the phase of the $BaAl_2Si_2O_8$ transition is an important issue. Therefore, a feasible solution to this problem is to reduce the sintering temperature of $BaAl_2Si_2O_8$ ceramics [78].

Table 3. Classification of sintering methods from the last few decades

Materials	Preparation Method	Years	Ref
Fly ash	Powder sintering technology	2002	[69]
Dicalcium silikat (Ca_2SiO_4)	Sintering method	2004	[16]
Alumina	Two-step sintering method	2008	[61]
MgO, TiO_2, and CoO	Conventional sintering method	2011	[62]
TiO_2	sintered through microwave and conventional processes	2012	[9]
CNTs and Al_2O_3 powders	Sintering method	2012	[32]
Terbium gallium garnet (TGG)	Co-precipitation method and sintering method	2013	[27]
Yttrium aluminum garnet ($Y_3Al_5O_{12}$, YAG)	Co-precipitation synthesis and two-step sintering	2013	[63]
Bi_2O_3, Na_2CO_3, K_2CO_3, $BaCO_3$, TiO_2, and Nb_2O_5	Two-step sintering method	2013	[60]
Eu, doping $(Lu, Gd)_2O_3$	The solid-state reaction method combined with vacuum sintering without sintering aids	2017	[29]
Cerium doped lutetium aluminum garnet single crystal	Sintering in an oxygen atmosphere and post hot isostatic pressing	2018	[30]
K2CO3, Na_2CO_3, and Nb_2O_5	Cold sintering assisted sintering	2018	[59]

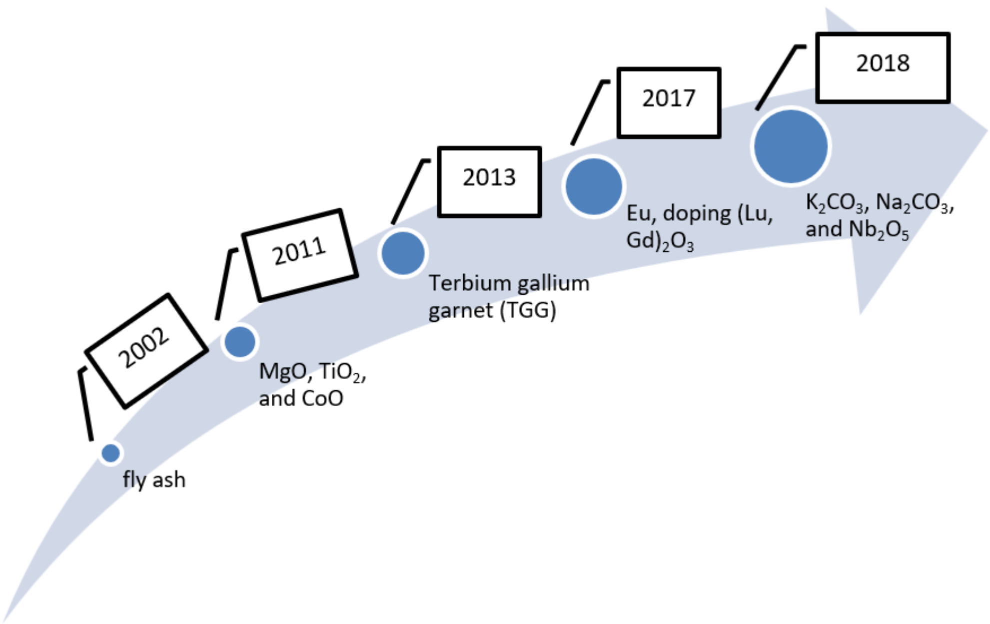

Figure 3. Technological developments for the Sintering method 2002-2018

2.3 Preparation of co-precipitation method

Various methods have been widely used, such as the sintering method [27], hot-pressing method [56], and co-precipitation method [79]. Of the various methods, coprecipitation is one of the easiest ways to make nanoparticles. The coprecipitation method can lower the reaction temperature at which the reagent mixture precipitates. This method is an easy way to synthesize highly reactive metal oxide nanopowders by low-temperature sintering [80]. The co-precipitation method of various types of ceramic based materials and their development from 2008-2019 as shown in Table 4.

Advanced ultra-high-strength steels are well suited for a wide range of engineering applications. Nanoscale coprecipitation reinforcement in steels has received increasing attention in recent years and it is only in the new era to develop advanced steels with a good combination of mechanical, weldable, and radial properties. This review focuses on recent advances in computational alloy design, nanostructure characterization, and the unique properties of newly developed nanoscale precipitation reinforced steels [81]. In particular, our emphasis is on developing materials with co-precipitation methods used to manufacture better ceramics for the future. developments with environmentally friendly materials are increasingly being developed with a wider variety of applications. The coprecipitation approach can produce an excellent combination of various properties resulting from the synergistic combination of several types of nanoparticles with different compositions, microstructures, and micromechanical properties [82]. Figure 4 shows technological developments in ceramic making using the Co-precipitation method from the last few decades.

Table 4. Classification of co-precipitation methods from the last few decades

Materials	Preparation Method	Years	Ref
$CaCu_3Ti_4O_{12}$ (CCTO)	Co-precipitation method	2008	[67]
Ni $(NO_3)_2$.$6H_2O$, Zn $(NO_3)_2$.$6H_2O$, and Fe $(NO_3)_3$.$9H_2O$	Co-precipitation method	2010	[65]
Yttria (Y_2O_3), aluminum nitrate nonahydrate ($Al(NO_3)_3{\cdot}9H_2O$, ammonium hydrogen carbonate (NH_4HCO_3), and ammonium sulfate $(NH_4)_2{\cdot}SO_4$)	Co-precipitation method	2012	[68]
Yttrium aluminum garnet ($Y_3Al_5O_{12}$, YAG)	Co-precipitation method and two-step sintering	2013	[63]
Terbium gallium garnet (TGG)	Co-precipitation method and sintering method.	2013	[27]
$MnSO_4$ H_2O, copper sulfate $CuSO_{45}H_2O$, and nickel sulfate $NiSO_{46}H_2O$	Co-precipitation and solid-state method	2014	[27]
Fe_2O_3/ TiO_2	Co-precipitation method	2015	[35]
Lu $(NO_3)_3$ and Eu $(NO_3)_3$	Co-precipitation method	2018	[31]
ZrO_2–Al_2O_3	Co-precipitation method	2019	[64]

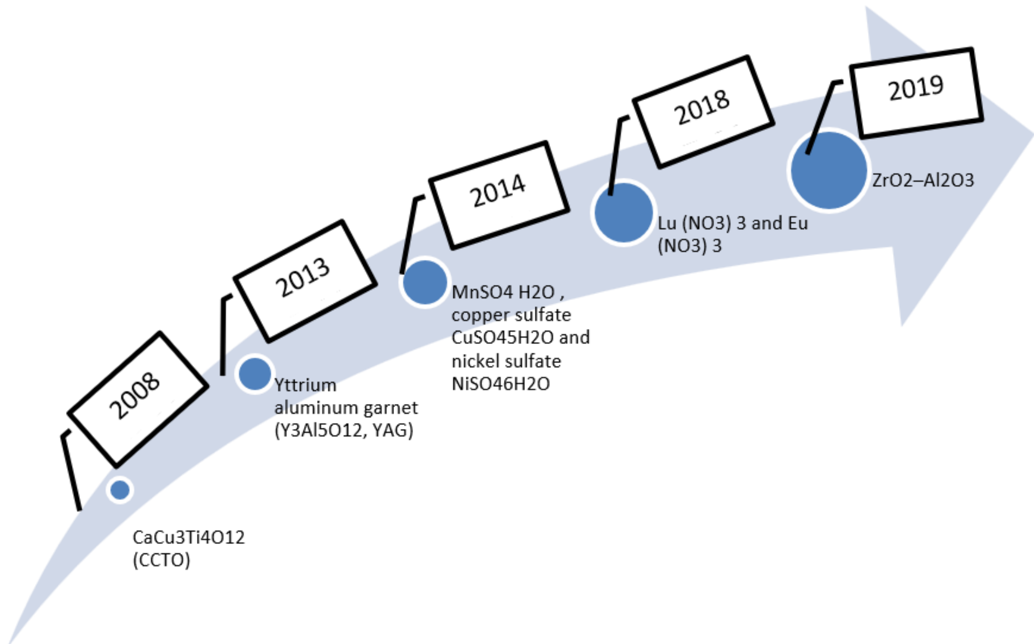

Figure 4. Technological developments use of Co-precipitation method 2008-2019

Zirconia-toughened alumina (ZTA) hardened alumina has been in great demand in recent years. The mechanical properties of aluminum oxide ceramics at room temperature are significantly improved by introducing a well-dispersed tetragonal zirconium oxide (t) polycrystal which transforms into a monoclinic (m) phase under loading [83]. Here, we present an industrial-scale coprecipitation route with ZTA synthesis and conventional sintering resulting in dense fine-grained composite materials yielding ZTA composites with high critical stress intensity factor coefficients [64]. The flow chart of the ZTA processing is depicted in Figure 5.

Deng-Feng et al. In 2013 reported Kinetic studies on Aging improvement in Cu-containing NTC ceramics prepared by the co-precipitation method, the structure, and properties of Mn2.15Cu0.4Ni0.45O_4 NTC ceramics were characterized using scanning electron microscopy, powder X-ray diffraction, temperature resistivity, accelerated aging assays within 125°C (aging temperature). The results obtained by the coprecipitation method showed a relatively low resistance deviation of 22.5% compared to 39.5% of the resulting resistance by the solid method [66].

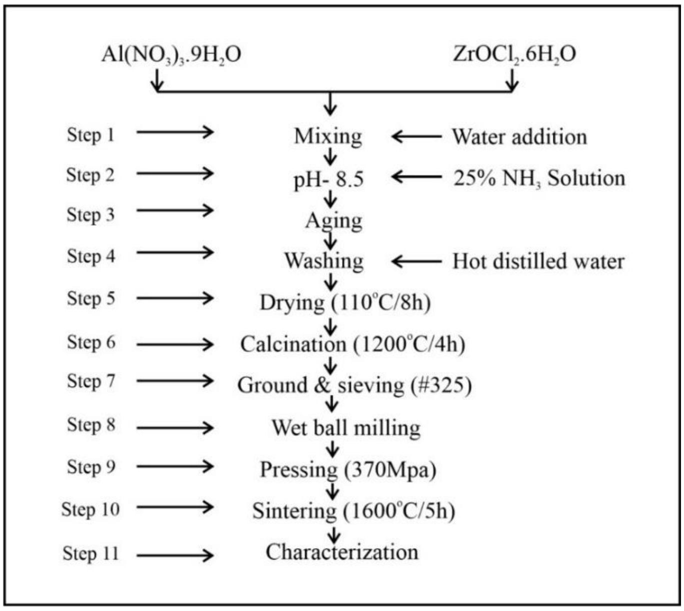

Figure 5. Process flow diagram of ZTA composites via co-precipitation method [64].

2.4 Solid-state method

Today the world has entered an environmental epoch, the environmental problems have attracted more and more attention from the international society. In response to this, the solid-state method has great developmental potential and wide industrial application prospects in promoting energy efficiency and reducing pollution. The classification of solid-state methods from various materials was reported from 2001 to 2017 presented in Table 5. In 2019, Hao et al. demonstrated Lithium metal titanate (Li_2TiO_3) ceramic pebbles were fabricated from the powder synthesized via a low-temperature solid-state precursor method [84]. The schematic illustration flowchart as shown in Figure 6.

So far, several studies have investigated the synthesis of Li_2TiO_3 nanoparticles by the solid-phase reaction. Therefore, improving solids methods for synthesizing nano-sized Li_2TiO_3 powders is a very meaningful task. Cold Solid Precursor (LTSSP) method was developed to produce Li_2TiO_3 nanopowder using H_2TiO_3 as a titanium source. Since H_2TiO_3 is an intermediate product of the industrial production of TiO_2, the LTSSP process is very economical and has the potential to be produced in large quantities [84].

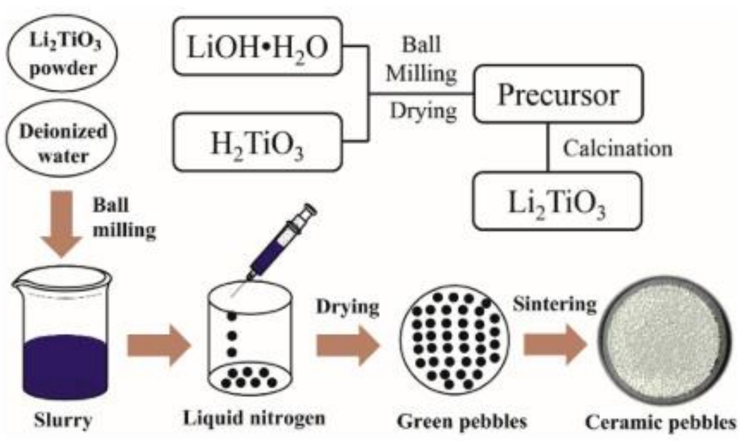

Figure 6. Fabrication flowchart of Li2TiO3 ceramic pebbles via low-temperature solid-state precursor LTSSP method

Table 5. Classification of solid-state methods from various materials reported in the last few decades.

Materials	Preparation Method	Years	Ref
MgTiO sintering 3–CaTiO temperature 3 microwaves	Solid-state method	2001	[14]
$CaCO_3$, TiO_2 (Aldrich) and Ta_2O_5, Nb_2O_5 (NFC, India)	Conventional solid-state ceramic route method	2002	[13]
Neodymium doped yttrium aluminum garnet (Y Al O) nanocrystalline	Solid-state laser nanocrystalline fabrication process	2002	[15]
$BiFeO_3$ ceramic	Conventional solid-state-reaction and mechanical activation assisted solid-state-reaction method	2008	[47]
Barium carbonate ($BaCO_3$), zirconium (IV) oxide (ZrO_2), and yttrium (III) oxide ($9Y_2O_3$)	Solid-state reactive sintering	2010	[49]
$BaCO_3$, $CaCO_3$, TiO_2, and SnO_2	The conventional solid-state reaction method	2012	[46]
Calcium titanate ($CaTiO_3$)	Conventional solid-state reaction method.	2013	[48]
Ceramics $Ba_2Zn_1xCaxWO_6$	Solid-state reaction	2014	[22]
$MnSO_4$ H_2O, copper sulfate $CuSO_{45}H_2O$ and $NiSO_{46}H_2O$	Co-precipitation and solid-state method	2014	[66]
Bi_2O_3, Al_2O_3, $BaCO_3$, and TiO_2	Solid-state reaction method and sol-gel method	2015	[45]
Eu, doping (Lu, Gd)$_2$O$_3$	The solid-state reaction method combined with vacuum sintering without sintering aids	2017	[29]

3. CONCLUSION AND FUTURE OUTLOOK

Various methods have been carried out in the process of ordering ceramics such as the sintering method, the hot-pressing method, the co-precipitation method, and the solid-state method have been discussed in this paper. In 2001 the hot-pressing method was used to manufacture ceramics made from B4C with doping (W, Ti) C until 2019 with SiAlCO ceramic raw materials. In 2002 the sintering method was used to manufacture ceramics with fly ash as raw material until 2018 with ceramic raw materials K_2CO_3, Na_2CO_3, and Nb_2O_5. In 2008 the co-precipitation method was used for the manufacture of ceramics using $CaCu_3Ti_4O_{12}$ (CCTO) as raw material until 2019 with ZrO_2 - Al_2O_3 ceramic raw materials. In 2001 the solid-state method was used for the manufacture of ceramics with MgTiO sintering 3 - CaTiO temperature 3 microwave raw materials until 2017 with European Union ceramic raw materials, with (Lu, Gd)$_2$O$_3$ doping.

Based on the above results it is known that the four methods have been used from several ceramic materials from the 2000s until now. However, the physical mechanism of these methods and the effects on the performance of ceramics remains to be further studied. In the future, it needs to be addressed: the preparation time needs to be shortened, material preparation cost reduced, and improve the properties of produced the ceramics, more advanced preparation methods can also be explored. There is still open research for further improving the properties of ceramics and the research should be attracted more and more attention to becoming an intense and worldwide activity. For the new application of ceramics, interdisciplinary research between physicists, chemists, materials scientists, and engineers is also needed. It is expected to promote the sustained and rapid growth of ceramic research and future easily large-scale production and application.

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