

Thermal stability of Al_2TiO_5 ceramics for new diesel particulate filter applications—a literature review

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The use of Al_2TiO_5 ceramics in diesel engine exhaust systems has been limited by the problem of thermal stress and thermal instability caused by the anisotropic thermal expansion between different materials. In order to avoid this problem, one of the choices is to develop low or zero-level thermal expansion materials that can be used, for example in diesel particulate filters (DPF), in which the original dimensions of the material are maintained, without being affected by thermal shock at high temperatures. For such applications, Al_2TiO_5 ceramic particulate filters must also have chemical inertness, thermal durability, high filtration efficiency, low pressure drop-, and adequate strength. In particular, DPF ideally combine low thermal expansion, low pressure drop for engine efficiency, high filtration efficiency, high strength, and low production cost. This study examined the publications and patents for thermal stability of Al_2TiO_5 ceramics with different inorganic materials having a low thermal expansion and high thermal shock resistance, suitable porosity and a narrow pore size distribution suitable for diesel exhaust filtration applications.

Key words : Al_2TiO_5 , low thermal expansion, thermal shock-resistant, thermal stability, decomposition.

Introduction

Aluminum titanate (Al_2TiO_5) ceramics are excellent thermal shock-resistant materials on account of their unique combination of low thermal expansion and low Young's modulus, which, allows for applications as an insulating material in engine components such as portliners, piston bottoms, turbochargers, and DPF etc. [1, 2]. However, Al_2TiO_5 materials have a relatively low mechanical strength due to microcracks induced by the high anisotropy of the thermal expansion coefficients which are -3.0 , $+11.8$ and $+21.8 \times 10^{-6}/\text{K}$ for its three crystallographic axes, respectively [3, 4]. Furthermore, pure Al_2TiO_5 tends to decompose into Al_2O_3 and TiO_2 at temperatures ranging from 800° to 1300°C [5, 6]. This decomposition occurs when the adjacent Al^{3+} (0.54 \AA) and Ti^{4+} (0.67 \AA) octahedra collapse because the lattice site occupied by the Al^{3+} ion is too large [7]. The thermal energy available from this collapse allows Al^{3+} to migrate from its position and causes structural dissolution to rutile (TiO_2) and corundum (Al_2O_3) [8]. Following decomposition, the material exhibits neither a low thermal expansion coefficient nor favorable thermal shock behavior, rendering it useless for DPF applications.

Thermal stability

The thermal stability of Al_2TiO_5 can be improved by

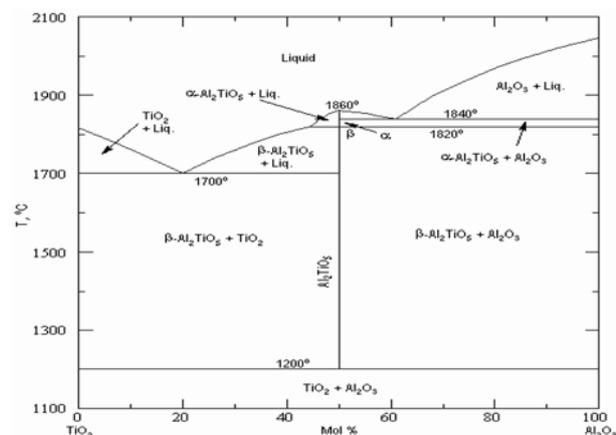


Fig. 1. Phase diagram of Al_2O_3 - TiO_2 system by Goldberg *et al* [9, 10].

the formation of solid solutions with MgO , Fe_2O_3 , or TiO_2 , which are isomorphous with the mineral pseudobrookite, such as Fe_2TiO_5 [11-15], MgTi_2O_5 [16-25], Ti_3O_5 (anosovite) [26] and MgAl_2O_4 (Spinel) [27-32].

This thermodynamic stabilizing effect is related to a decrease in the decomposition temperature of isostructural compounds during cooling as shown in Fig. 2. The compounds MgTi_2O_5 and Fe_2TiO_5 decompose to $\text{MgTiO}_3 + \text{TiO}_2$ below 700°C and $\text{Fe}_2\text{O}_3 + \text{TiO}_2$ at 565°C , respectively, whereas Al_2TiO_5 decomposes to Al_2O_3 and TiO_2 below 1300°C [12-15, 33]. Furthermore, the thermal stability of Al_2TiO_5 ceramics with the solid solution Fe_2TiO_5 , MgTi_2O_5 , or Ti_3O_5 is unsuitable after a long term durability test at the critical temperature at 1100°C for 100-300 h [34-37].

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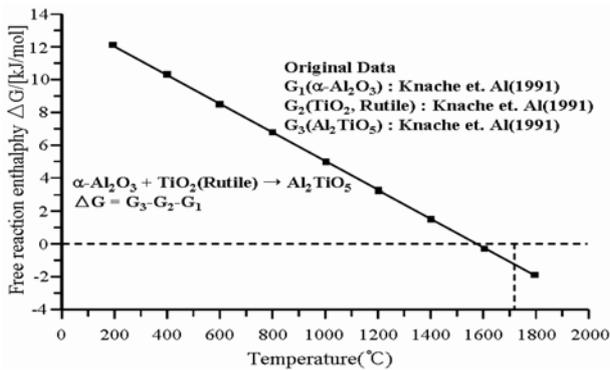


Fig. 2. Free energy ΔG of Al_2TiO_5 from $\alpha\text{-Al}_2\text{O}_3$ and TiO_2 [36, 37].

Polycrystalline Al_2TiO_5 can also be stabilized by limiting its grain growth [38-40]. Another source of stabilization is the limitation of grain growth of Al_2TiO_5 through the addition of additives such as SiO_2 [41], ZrO_2 [42, 43], mullite [33, 44-62] and ZrTiO_4 [63-68] most of which do not form a solid solution with Al_2TiO_5 but rather inhibit Al_2TiO_5 decomposition. However, the additives, SiO_2 and ZrO_2 , do not have a significant effect on the thermal stability of Al_2TiO_5 , even after a long annealing test at 1100°C for 100-300 h [36]. On the other hand, the addition of mullite or ZrTiO_4 not only restrains decomposition but also increases the thermal stability at 1100°C [15, 69].

Mullite, a second phase, has been used to reduce microcracking as well as grain growth of the Al_2TiO_5 phase and eventually improve the mechanical behavior in the temperature range 1300 and 1450°C , according to a compressive mechanical test that was correlated to the microstructure. The positive effects of the thermal treatment and thermal expansion behavior are due to the micro-crack system of Al_2TiO_5 ceramics at grain boundaries as shown in Fig. 3. It appears that the high thermal expansion of a Al_2TiO_5 single crystal (see Fig. 3, above, $9.70 \times 10^{-6}/\text{K}$) and low thermal expansion of sintered Al_2TiO_5 ceramics (below) are due to the effects of grain boundary micro-cracking caused by the large thermal expansion anisotropy of the crystal axes of the Al_2TiO_5 phase. During the reheating run, the individual crystallites expanded at low temperature. Therefore, the solid volume of the specimen expands into micro-cracks, where as the macroscopic dimensions remained relatively unchanged. As a result, the material expanded slightly up to 1000°C and the micro-cracks closed at higher temperatures. This result is closely related to thermal expansion curves that were relatively steep [6, 35-37].

Al_2TiO_5 - mullite (ATM) ceramics

Most Al_2TiO_5 - mullite (ATM) ceramics used in DPF applications are prepared by an extrusion method after a sintering reaction from the individual minerals and after adjusting the main composition of $\text{Al}_2\text{O}_3/\text{TiO}_2/\text{SiO}_2$ to form Al_2TiO_5 -mullite and a glass phase such as; kaolin [70], feldspar [71-79], SrO feldspar [45, 49, 53, 54],

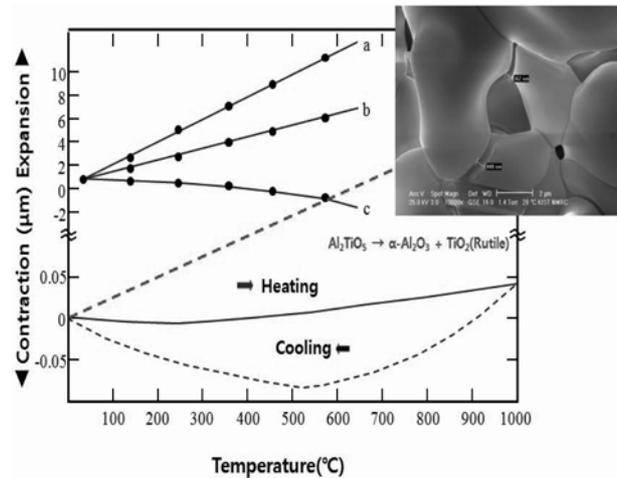


Fig. 3. Thermal expansion of single crystal (above) and sintered Al_2TiO_5 (below) and microstructure of Al_2TiO_5 ceramics.

amorphous SiO_2 [80], boehmit [57], inorganic micro balloons [56], SE_2O_3 (SE_2O_3 : 0.1-10 wt%, SE: Y, Yb, Dy, Ho, Tm, Lu) [81], cordierite-spinel [57, 82], spinel [83, 84], $\text{Na}_{0.6}\text{K}_{0.4}\text{AlSi}_3\text{O}_8$ [85, 86], and Al_2O_3 [87] etc..

All ATM composites exhibit reduced low thermal expansion coefficients with increasing Al_2TiO_5 content accompanied by a pronounced large hysteresis area, as shown in Fig. 4. The ATM materials showed low thermal expansion up to 700°C . However, the temperature hysteresis increased when the temperature was further increased. This was attributed to the onset of mechanical healing of the micro cracks as the temperature was raised to more than 900°C , and the re-opening or refracting of cracks that occurred when cooled to $< 730^\circ\text{C}$. Even at 1000°C the slope of the ATM1 materials sintered at 1600°C remained flat in terms of zero level thermal expansion during heating, which suggests that a significant proportion of the micro-cracks remain open (see Fig. 4). The thermal expansion coefficient of ATM materials sintered at 1600°C for 6 h were $1.09 \times 10^{-6}/\text{K}$ for ATM1, $2.50 \times 10^{-6}/\text{K}$ for ATM2, $4.06 \times 10^{-6}/\text{K}$ for ATM3 and $5.48 \times 10^{-6}/\text{K}$ for ATM5 at temperatures that increased from 20 to 1000°C [69].

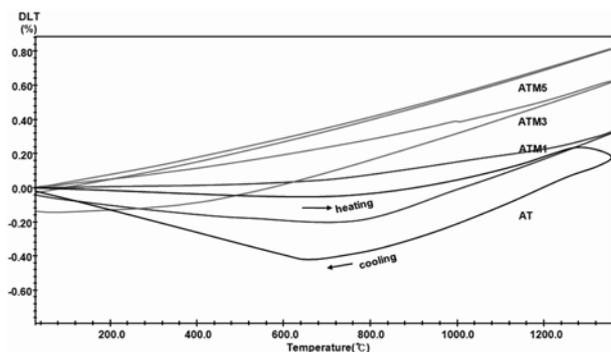


Fig. 4. Thermal expansion curves of AT and ATM ceramics sintered at 1600°C for 6 h.

The largest increase in strength occurred with the synthesized Al₂TiO₅ powder, particularly using Al₂O₃, MgO or ZrO₂. The increase in mechanical strength reported for this material was linked microstructurally to the observation of fine Al₂O₃, MgAl₂O₄, or ZrO₂ particles at the grain boundaries [37]. Such a distribution of fine particles at the grain boundaries would prevent grain growth and reduce microcracking, thereby increasing the strength [31, 33]. SiO₂ additions improve the strength of reaction-sintered material to a limited amount of 3%. This was attributed to the formation of a grain boundary liquid phase during sintering [7]. Pena *et al.* [90] examined the properties of an Al₂TiO₅-mullite-ZrO₂ mixture and obtained a strength of 30 MPa, which represents a 10-fold improvement over their pure Al₂TiO₅ material. Yano *et al.* [91] reported a mechanical strength of approximately 100 MPa for material containing 25 vol% mullite, which coincided with the point at which decomposition had been completely controlled. Morishima *et al.* [92] reported a strength of 70 MPa for an Al₂TiO₅-mullite composite material containing 91 vol% Al₂TiO₅, but this material did not show any retention of strength.

The thermal shock resistance of Al₂TiO₅ ceramics is influenced not only by characteristics such as the thermal expansion coefficient, thermal conductivity, strength, modulus of elasticity, Poisson's ratio etc. of the material but also by the size and profile of the product made from them as well as from the heating and cooling states, and heat transfer speed [93]. Such effects and the particle size often govern the sensitivity of the physical properties, including the coefficient of thermal expansion, porosity, or pore size, low firing temperature, which are undesirable for DPF manufacture. In addition, the desired properties for use as a DPF use are not expected to be achieved. Furthermore, the phase stability and physical/mechanical properties make Al₂TiO₅ based materials very difficult to control for the complex interrelationships between microcracking.

In general, thermal shock resistance is a property that is difficult to quantify, and it is usually expressed in terms of a number of empirical resistance parameters, which are dependent on the conditions imposed. However, an examination of strength retention after quenching can be performed. For high temperature applications,

long-annealing thermal durability, cycle thermal stability and residual mechanical properties are very important if these materials are to be used between 1000 °C and 1300 °C. Attempts to improve the thermal durability of Al₂TiO₅ between 750° and 1400 °C are still under investigation. In particular, Al₂TiO₅-mullite (ATM) ceramics have a very high volumetric heat capacity (approximately 3.9 to 4.0 J cm⁻³ for fully dense ATM at 800 K) in combination with a low CTE. In addition, ATM ceramics have excellent chemical durability and high melting point. Table 1 summarizes the phase compositions, thermal and physical properties of ATM materials (1600°C/2h) after various heat treatments.

However, in the manufacture of ATM ceramics involving sintering temperatures greater than 1600 °C, such high heating temperatures add to the manufacturing and final product cost. Furthermore, many methods for making Al₂TiO₅-based ceramics require the use of pre-reacted Al₂TiO₅ and/or mullite powders, which also increase the manufacturing cost. Moreover, the desired properties for DPF use are not expected to be achieved.

Some approaches have employed to reduce the sintering temperature. These include the addition of chemical components, such as inorganic micro balloons (1450-1600 °C) [56], an amorphous phase (1375-1450 °C) [80], SE₂Ti₂ (1400-1650 °C) [81], anatase and beohmite (1375-1500 °C) [57, 94-97] etc. In general, raw materials, such as alkali feldspar SrO feldspar, kaolin, silicate, aluminosilicate, magnesium silicate, hematite, rutile, SE₂O₃, and inorganic micro balloons etc. are added to form a solid solution Al₂TiO₅-mullite or glass phase based ceramics by reaction sintering.

Al₂TiO₅-ZrTiO₄ (ATZ) ceramics

Al₂TiO₅-ZrTiO₄ (ATZ) ceramics also have low thermal expansion (0.1-1.3 × 10⁻⁶K⁻¹), and a high melting temperature (> 1500 °C) [63, 64, 98]. Al₂TiO₅-ZrTiO₄ (ZAT) based ceramics with increasing Al₂TiO₅ content exhibit lower thermal expansion coefficients and a pronounced large hysteresis area. The composition is preferably made by forming a mixture of 50-90 vol.% Al₂TiO₅ materials which show a negative and ultra low thermal expansion up to 700-1000 °C. However, when the temperature is increased further, the thermal expansion and hysteresis

Table 1. The Phase Compositions, Thermal and Physical Properties of ATM Materials (1600 °C for 2 h)

Material	Mullite content [%]	Phase		Sinter density [g/cm ³]			Thermal expansion coefficient [10 ⁻⁶ K ⁻¹]		Young's modulus [GPa]		
		1600/6 h	1100/100 h	1600/6 h	1100/100 h	**cycles	1600/6 h	1100/100 h	1600/6h	1100/100h	**cycles
AT	0	AT	A+T	3.1	-	-	0.68	6.15	20	-	-
ATM1	10	*AT+M	*AT+M	3.3	3.71	3.63	1.09	1.49	23	38.9	35.0
ATM2	20	*AT+M	*AT+M	3.5	3.57	3.53	2.50	3.03	40	44.7	41.7
ATM3	30	*AT+M	*AT+M	3.41	3.46	3.40	4.06	3.59	65	70.9	67.4
ATM5	50	*AT+M	*AT+M	3.4	3.50	3.30	5.48	5.36	80	78.8	78.5

*AT : Al₂TiO₅, M : Mullite, A : Al₂O₃, T : TiO₂

**cycles : 750-1400-750 °C for 23 cycles

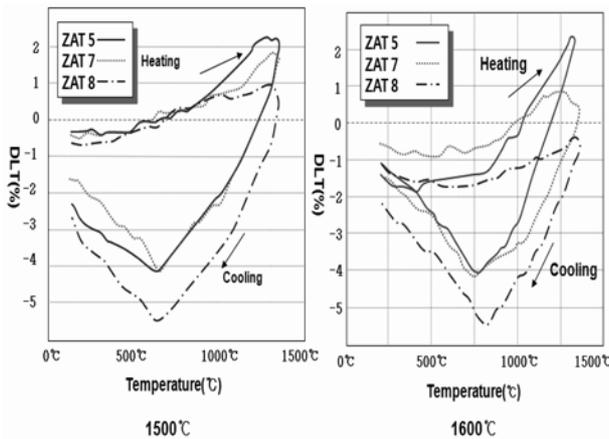


Fig. 5. Thermal expansion curves of ZAT ceramics sintered at 1500 °C and 1600 °C for 2 h.

increased relatively, as shown in Fig. 5 (see Table 2). This was attributed to the onset of mechanical healing of micro-cracks with heating to > 600 °C and their re-opening or refracturing that occurs when cooled to below 730 °C. However, the phase stability of the Al_2TiO_5 phase in the ZAT matrix after a long term durability test at 1100 °C and a cyclic thermal shock test between 750-1400-750 °C was insufficient for DPF applications as shown in Table 2 [64-66].

Therefore, the phase stability of Al_2TiO_5 at high temperature should be improved by a thermodynamic effect with the formation of solid solutions and also kinetically with the limitation of grain growth of Al_2TiO_5 in the matrix. Otherwise, Al_2TiO_5 ceramics no longer exhibits either a low thermal expansion coefficient or favorable thermal shock behavior, rendering them useless for DPF applications. Therefore, there is a need for new stabilized Al_2TiO_5 - ZrTiO_4 (ZAT) based ceramics that can be manufactured at lower sintering temperatures with properties that are useful for high temperature filtration applications. In particular, it is important to prepare low thermal expansion ceramics with the appropriate microstructures composed essentially of Al_2O_3 , TiO_2 , SiO_2 , and ZrO_2 where the crystalline phases of the fired product consist primarily of Al_2TiO_5 and ZrTiO_4 , or a solid solution such as mullite and glass phase.

In order for a solid solution to form, the solute element must have approximately the same ionic radius and similar (\pm valence) atomic charge as the element that it is replacing (see Table 3). Similar crystal structures are also helpful but not always necessary. Fe^{3+} with a radius of 0.64 Å, readily forms a solid solution with the Al^{3+} in Al_2TiO_5 , which has a radius of 0.54 Å. Therefore, other elements such as Cr^{3+} (0.69 Å) and Mg^{2+} (0.72 Å) can also form compatible solutions with Al^{3+} . A similar case could be

Table 2. Phase Compositions, Thermal and Physical Properties of ZAT Materials (1600 °C/ 2 h)

Materials	Al_2TiO_5 contents [%]	Phases		Sinter density [g/cm ³]	Thermal expansion coefficient $\alpha_{25-1350}$ [10^{-6}K^{-1}]	Decomposition content of Al_2TiO_5 after thermal shock test [%]	
		1600/2h	1100/100h			1100/100h	750-1400-750 °C for 23 cycles
AT	100	AT	AT+A+T	3.68 (93.2)	0.68	90	70
ZAT5	50	AT+h-ZT	AT+h-ZT+T+A	4.40 (96.3)	1.3	20	10
ZAT7	70	AT+h-ZT	AT+h-ZT	4.09 (97.3)	1.2	10.5	15
ZAT8	80	AT+h-ZT	AT+h-ZT+T	3.95 (98.5)	0.9	65.0	15
ZAT9	90	AT+h-ZT	AT+h-ZT+T+A	3.84 (98.1)	0.2	70.2	20

AT : Al_2TiO_5 , h-ZT : High-ZrTiO₄, A : Al_2O_3 , T : TiO_2
() : Relative density [%]

Table 3. Ionic Radius Condition for Al_2TiO_5 , A_2BO_5 Solid Solutions

Ion A, Al^{3+} (0.54 Å)	Size difference/ Solid solution	Ion B, Ti^{4+} (0.61 Å)	Size difference/ Solid solution	
Cu^{+3} (0.54 Å)	3.57	Ge^{4+} (0.53 Å)	$\text{Al}_2\text{Ti}_{1-y}\text{Ge}_y\text{O}_5$	
Co^{+3} (0.55 Å)		Mn^{4+} (0.53 Å)		
Ni^{+3} (0.56 Å)		Ti^{4+} (0.61 Å)	Ti_3O_5	
Cr^{+3} (0.62 Å)	12.9	Mo^{4+} (0.65 Å)	$\text{Al}_2\text{Ti}_{1-x}\text{Zr}_x\text{O}_5$	
Ga^{+3} (0.62 Å)		W^{4+} (0.69 Å)		
Fe^{+3} (0.65 Å)	16.9	Sn^{4+} (0.69 Å)		$\text{Al}_{2(1-x)}\text{Mg}_x\text{Ti}_{1-y+x}\text{Ge}_y\text{O}_5$ (GeO_2 , MgO) ($\text{Mg}_{0.5}\text{Fe}_{0.5}$) Ti_2O_5
Ti^{+3} (0.67 Å)		Hf^{4+} (0.71 Å)		
Mo^{+3} (0.69 Å)	28.0	Zr^{4+} (0.72 Å)		
Sc^{+3} (0.75 Å)		Mg^{2+} (0.72 Å)		
Sb^{+3} (0.76 Å)		Fe^{4+} (0.65 Å)		
Yb^{+3} (0.87 Å)	25	Ce^{4+} (0.87 Å)	$\text{Mg}_x\text{Al}_{2(1-x)}\text{Ti}_{(1+x)}\text{O}_5$	
Mg^{2+} (0.72 Å)		Th^{4+} (0.94 Å)		

made for Si^{4+} , Zr^{4+} , etc., substituting for Ti^{4+} , it is believed that a small amount of oxide element may diffuse between the phases during sintering/calcining, resulting in a more complex solid solution than intended for the stability of Al_2TiO_5 - ZrTiO_4 (ZAT) composites.

The addition of excess starting oxides can also give the desired phase assemblages and subsequent beneficial properties. Small quantities of additives, such as Fe_2O_3 and MgO , can be added as a component to Al_2TiO_5 in any of the routes described above. Such additives maintain the properties of Al_2TiO_5 , and it was found that 1 to 5 wt% addition of, for example, Fe_2O_3 , MgO , or mixtures thereof are advantageous which can be responsible for its phase stability and controlled microcracking behavior due to the decrease in crystal anisotropy. In addition, during calcining or sintering, cation diffusion between components can occur such that a small amount of ZrO_2 may go into solution $\text{Al}_2\text{Ti}_{1-x}\text{Zr}_x\text{O}_5$ imparting beneficial properties.

Al_2TiO_5 - ZrTiO_4 -mullite (ATZM) ceramics

An excellent thermal shock-resistant material based on Al_2TiO_5 - ZrTiO_4 -mullite or other oxide composites of various compositions can be fabricated by a sintering reaction from the individual oxide sources and adjusting the $\text{Al}_2\text{O}_3/\text{TiO}_2/\text{SiO}_2$ and ZrO_2 ratios. Fig. 6 shows the solid state relationships in the plane Al_2O_3 - TiO_2 - ZrO_2 - SiO_2 system. The diagrammatic representation of the solid state-compatibility relationships shows the part of the system where Al_2O_3 is one of the phases. $\text{A}_3\text{S}_2 = \text{Al}_6\text{Si}_2\text{O}_{13}$ (mullite); $\text{AT} = \text{Al}_2\text{TiO}_5$; $\text{ZT} = \text{ZrTiO}_4$; $\text{A} = \text{Al}_2\text{O}_3$; $\text{Z} = \text{ZrO}_2$; $\text{S} = \text{SiO}_2$; $\text{ZS} = \text{ZrSiO}_4$. The composition can be made preferably by forming a mixture of the equivalent of 50-90 vol.% Al_2TiO_5 or a solid solution with a substantial amount of Al_2TiO_5 in the solid solution, and 10-40 vol.% of ZrTiO_4 followed by heating the mixture to 1250 °C or higher [85, 99, 100].

The presence of 10-20 wt% ZrSiO_4 helps densify these materials and increase the temperature for Al_2TiO_5

formation [101]. During the reaction-sintering process, ZrSiO_4 decomposes to form ZrTiO_4 as a transitory phase. Temperatures > 1450 °C are needed to dissociate the compound yielding Al_2TiO_5 , ZrTiO_4 , mullite and ZrO_2 . These composites can be obtained at 1450 °C. The temperature should not be increased to 1500 °C because this produces an appreciable amount of glass phase accompanied by the disappearance of mullite.

The inorganic micro balloons containing 63.2 wt% SiO_2 and 34.0 wt% Al_2O_3 can be reacted with an aluminum source, zirconia source, and titanium source to form Al_2TiO_5 , ZrTiO_4 , and mullite-based porous ceramics at low sintering temperatures, 1350-1500 °C. If the melting point of inorganic balloons is low, there is a tendency for the micro balloons to melt at 1100-1300 °C, allowing the pores to contact before the Al_2TiO_5 is formed. Fig. 7 also shows the solid state relationship of Al_2O_3 - TiO_2 - ZrO_2 - SiO_2 system.

Raw materials for new DPF ceramics

ZAT-forming raw materials are (1) oxide sources that react to form ZrTiO_4 and Mg or Fe stabilized Al_2TiO_5 phases, and/or (2) partially or completely pre-reacted ZrTiO_4 and Mg or Fe stabilized Al_2TiO_5 powders. The alumina source is a powder, that when heated to a sufficiently high temperature in the absence of other raw materials, yields substantially pure aluminum oxide, that includes alpha-alumina, a transition alumina such as gamma-alumina or rho-alumina, boehmite, aluminum hydroxide, and mixtures thereof. The morphology of alumina has to be tabular and the particle size should be sufficiently large for microcracking to be induced in the final structure. A particle size of between 10-25 micrometres is suitable. Hematite is recommended as a source of the iron oxide. A suitable titania source is rutile and anatase with a particle size of approximately 7-15 micrometres. The silica sources can include amorphous SiO_2 such as cristobalite, Kaolin (SiO_2 46%, Al_2O_3 39%, Fe_2O_3 0.8% etc.), and inorganic micro balloons and the ZrO_2 sources can include tetragonal

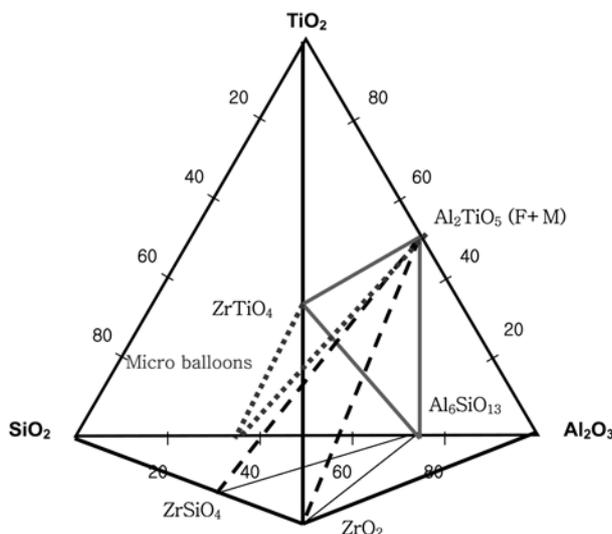


Fig. 6. Solid state relationship of Al_2O_3 - TiO_2 - ZrO_2 - SiO_2 system.

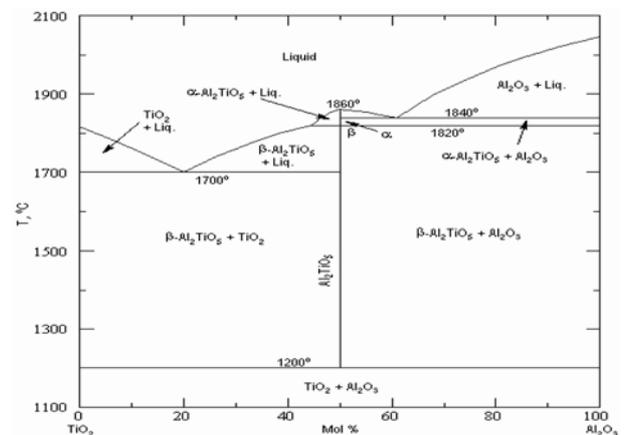


Fig. 7. Solid state relationship in the phase of the Al_2O_3 - TiO_2 - ZrO_2 - SiO_2 system.

and cubic forms stabilized by the addition of small amounts of CaO, Y₂O₃, or MgO. The silica and zirconia sources also include ZrSiO₄ (Zircon) which has 45.02 wt% of Zr and 17.67 wt% of Si. However, all material compositions, which are protected by intellectual property should not be considered for the current DPF products based on Al₂TiO₅ and the mullite phase. Therefore a thorough patent literature survey should be performed. In particular, the survey should examine the most important requirements related to Al₂TiO₅ ceramics with different inorganic materials with a low thermal expansion and high thermal shock resistance, suitable porosity and a narrow pore size distribution for diesel exhaust filtration applications under consideration of the following points; maximum operation temperature (1100-1200 °C), long durability of microstructure, CTE (WAK): $< 1.5 \times 10^{-6} \text{K}^{-1}$, good mechanical strength (50-70 MPa), excellent chemical resistance, and excellent thermal shock resistance ($\Delta T = > 1,000 \text{ °C}$) etc.

Conclusions

Because the near or zero thermal expansion of anisotropic Al₂TiO₅ materials minimizes thermal stress in a body, there has been considerable effort in developing low-expansion materials for severe thermal shock applications which is the rational approach to the thermal stabilization of composites. Pure Al₂TiO₅ tends to decompose reversibly into Al₂O₃ and TiO₂ at temperatures ranging from 800 to 1300 °C during cooling below the equilibrium temperature of 1280 °C. After decomposition, the material no longer exhibits either a low thermal expansion coefficient or favorable thermal shock behavior. A literature survey of Al₂TiO₅-mullite and Al₂TiO₅-ZrTiO₄ ceramics with low thermal expansion and good thermal shock resistance, suitable porosity and a narrow pore size distribution for diesel exhaust filtration applications was performed.

Porous cordierite (2MgO·2Al₂O₃·5SiO₂) ceramics have long been used as the cost-effective materials of choice for high temperature filtering applications, such as flow-through and wall-flow filters, on account of their combination of good thermal shock resistance, filtration efficiency, and durability under most operating conditions. However, under certain circumstances cordierite filters are susceptible to damage and some have even failed catastrophically. Occasional thermal runaway occurs during uncontrolled regenerations resulting in localized cordierite phase melting. Another factor contributing to failure occurs when metallic impurities from the engine oil, catalytic additives or corroded metal from the exhaust port liners are introduced into the filter during operation. Typically, at temperatures exceeding 1300 °C, these metals form oxides that react with the cordierite structure. Evidence of the failed material is usually small holes on the filter where the metal initially deposits and reacts causing corrosion and melting of the material.

Recently, silicon carbide (SiC) has been used as an alternative to cordierite in the fabrication of diesel

particulate filters. However, SiC is costly and must be segmented due to its inherent high coefficient of thermal expansion (CTE) and poor thermal shock resistance. Therefore, there is a need for a ceramic that is suitable for high temperature applications with all the advantages of cordierite but without the disadvantages. Furthermore, new materials based on Al₂TiO₅-ZrTiO₄-mullite (ATZM) or Al₂TiO₅-ZrTiO₄-ZrO₂ (ATZZ) composition for DPF must not infringe existing patents.

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