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Aluminum titanate based ceramics from aluminum sludge waste

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A R T I C L E I N F O

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This work aims at obtaining aluminum titanate-based ceramics (Al_2TiO_5: AT) composites from industrial wastes. Al-sludge waste and rutile ore were used as rich sources of alumina and titania instead of pure materials. Sludge-(0–40 wt%) rutile mixtures were mixed, formed and fired at 1350 °C for various times. Phase composition, microstructure, densification, mechanical and thermal behaviors of the obtained AT composites have been investigated. Complete conversion of the starting materials to AT with bulk density of 3.199 g/cm^3, compressive strength and modulus of rupture of 326.425 MPa and 30.84 MPa, respectively and very low CTE ($-0.927*10^{-6}$ K^{-1}) were achieved by firing the sludge-(30 wt%) rutile at 1350 °C for 4 h. These results suggest that the obtained AT-ceramics from Al-sludge waste-rutile ore are a promising and an ecofriendly route.

1. Introduction

Aluminum titanate (Al_2TiO_5: AT) is an excellent thermal shock resistant and refractory material with enhanced characteristics. It has a great interest for high temperature applications owing to its low thermal expansion coefficient ($0.2*10^{-6}$ to 10^{-6} °C^{-1}), high melting point (about 1860 °C), high temperature resistance, low thermal conductivity (0.9–1.5 W m^{-1} K^{-1}), low elastic modulus, high hardness, high strain to fracture, chemical inertness, good corrosion resistance, slugging resistance, alkali resistance, non-wetting with most metals and has low weight [1–5]. Hence, it is required in various areas of modern and engineering industries. Due to their exciting properties, AT based ceramics are widely used in several fields of steel, ceramic and refractory, metallurgy, glass, military, biomedical and tri-biological applications [6]. Moreover, AT is recommended for numerous applications in which high wear resistance, thermal insulation and thermal shock resistance are required, for example, thermal and corrosion resistant coatings, catalytic carrier, spacing rings of catalytic converters, and insulating components in automotive engines such as manifolds, port liners, head of the piston, soot particulate filter and cylinder in diesel engines [3,6,7]. Also, AT is used in foundry crucibles, launders, nozzles, riser tubes, pouring spouts, thermocouple components, non-wetting surfaces for molten non-ferrous metallurgy, master molds for the glass industry, textile manufacturing components and tooling, roller and bearings as well as much more structural applications [8–11]. Furthermore, AT is a good substitute for the machinable BN-ceramics, which are used as an insulating substrate instead of the high expensive one used in current microelectronics industry [12]. Consequently, the development of new low-cost machinable ceramics is consistently required.

In spite of all this, the wide use of this material is restricted to two obvious drawbacks. The first one deals with the weak mechanical strength resulting from the strong thermal expansion anisotropy causing micro-cracking [7], in which the thermal expansion coefficients of AT along the three crystalline axes are α_a=$9.8*10^{-6}$ k^{-1}, α_b=$20*10^{-6}$ k^{-1} and α_c=$-1.4*10^{-6}$ k^{-1}. In addition, these microcracks are also responsible for their low thermal expansion and the excellent thermal shock resistance [13]. The second is the thermal instability of Al_2TiO_5 which decomposes into the starting oxides of α-Al_2O_3 and TiO_2 (Rutile) at temperatures between about 800 and 1280 °C [3,7] due to the eutectoid reaction [8]. In order to overcome these shortcomings and improve AT ceramic properties, much work has been done by doping this system with some oxide additives (single and compound additives). Earlier studies have shown that the mechanical strength and thermal stability can be improved by the addition of dopants such as MgO, Fe_2O_3, CaO, La_2O_3, SnO_3, Y_2O_3, or SiO_2 or by the addition of suitable second-phase materials like Al_2O_3, ZrO_2, MnO, $FeSi_2$·SiO_2, kaolinite ($2Al_2O_3·3SiO_2·2H_2O$), talc ($Mg_3Si_4O_{10}(OH)_2$) and mullite ($3Al_2O_3·2SiO_2$) [3–7,11,14–20]. Another proposal for improving the strength is through the reduction of the microcracks volume. This can be achieved by decreasing the grain size in the microstructure of the sintered objects to be smaller than the critical grain size (2 µm) [14]. However, this course is difficult to accomplish because a grain growth happens during the sintering process.

On the other hand, it has been found that the process of decomposition in metastable Al_2TiO_5 is reversible and the reformation can

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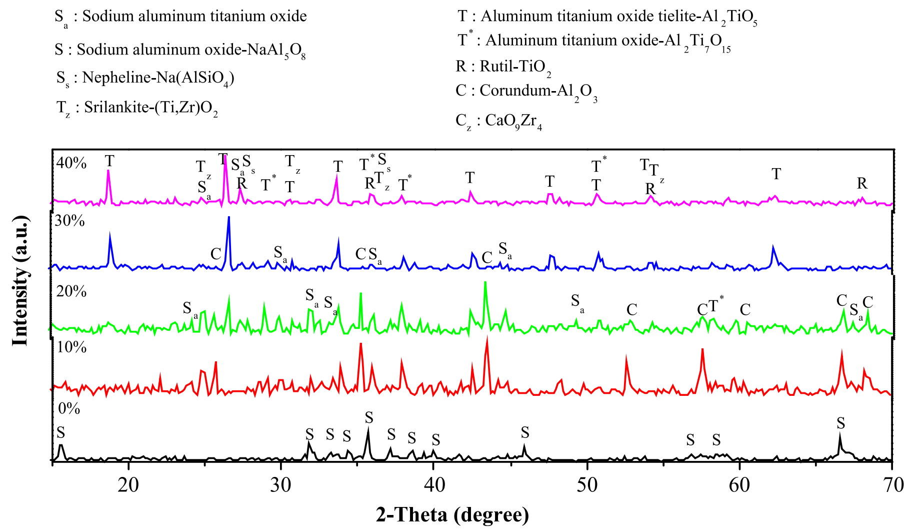

Fig. 1. XRD patterns of the fired sludge/rutile batches at 1350 °C for 2 h.

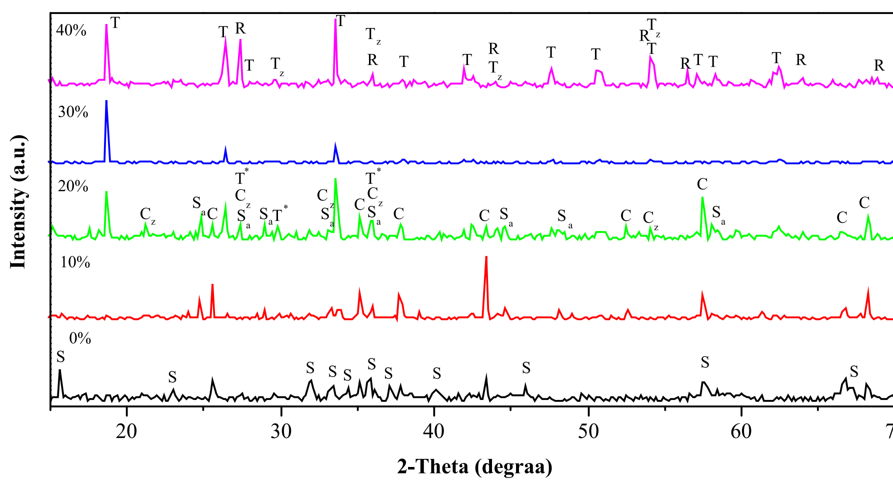

Fig. 2. XRD patterns of the fired sludge/rutile batches at 1350 °C for 4 h.

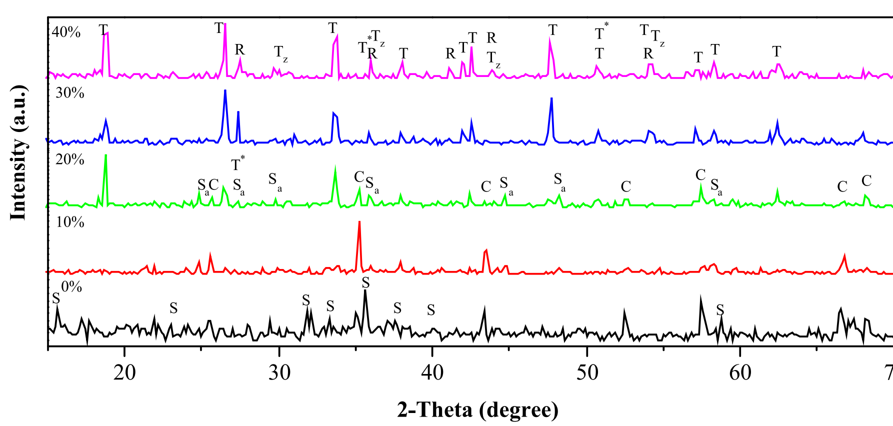

Fig. 3. XRD patterns of the fired sludge/rutile batches at 1350 °C for 6 h.

occur readily when the decomposed AT is re-heated above 1300 °C [21]. In addition, "self-healing" of cracks in AT has been observed at elevated temperature [22].

Generally, aluminum titanate can be prepared by several methods such as sol–gel [23], atmospheric plasma Spray (APS) [24], spark plasma sintering (SPS) [25], melt synthesis [26], impregnation [27,28], and precipitation and co-precipitation methods [18]. However, production of aluminum titanate ceramics adopting the aforementioned methods requires high expensive starting materials and/or a complicated apparatus. Consequently, a continual search for a simple and a low cost method is required. One of such effective methods is solid state reaction sintering. This method has many advantages. It does not need expensive starting materials or toxic chemicals, consumes less energy, and is a simple fabrication process and ecofriendly method. Moreover, it has the capability to produce nearly net-shaped objects and materials of controlled, uniform porosity and high strength. Hence, these