ABSTRACT

Wastes generated from different manufacturing processes and energy production units cause numerous environmental and health issues. Instead of landfilling, the waste can be recycled or reused to produce marketable value-added products with demand. Furthermore, the safe recycling of industrial by-products or wastes is essential and even vital at present for our society with the growing volume of waste generation. Ceramic industries are attracted to waste recycling perceptions. From this eco-friendly propensity, in the last two decades, an increasing number of studies have been demonstrated the possibility to use alternative ingredients in place of conventional raw materials (e.g., most common ternary clay-quartz-feldspar system) for the fabrication of ceramics. However, industrially produced ceramics from waste ingredients are not yet widely matured. Numerous conditioning features, like the compatibility between natural raw materials and wastes, complicated process, constant chemical compositions, availability, and the pre-treatments of the wastes, have limited the applications. The present work aims to evaluate the feasibility of using wastes, like rice husk ash (RHA), fly ash (FA), eggshell (ES), seashell, and refractory grog for the fabrication of ceramics. Facile, eco-efficient, and economical routes are adopted for the synthesis of sustainable ceramics like sol and nano-silica, the foam of silica and mullite, castable refractory, wollastonite, tile, ceramic board, and insulation refractory.

Nano silica and silica sol are successfully synthesized through an alkali extraction process using waste RHA. The estimated cost of RHA derived amorphous nano-silica, 7.5 wt.% silica, and 30 wt.% silica-containing sol are approximately 37.3 $ per kg, 2.86 $ per liter and 9.35 $ per liter, respectively. Silica and mullite foam ceramics are fabricated without using any pore producing additive or agent, in order to avoid the emission of greenhouse gases (mainly CO_2) from the matrix. Silica foams with above 70% of open porosity are prepared using RHA extracted nano-silica through control compaction and at low foaming

temperature (550°C/30 min). Mullite ($3Al_2O_3·2SiO_2$) foam ceramics are synthesized via a simple slip-casting method using ~7.5 wt.% silica-containing sol with a stoichiometric amount of reactive alumina. The single-phase mullite foam is formed at 1300°C, with retaining ~75.99 % total porosity.

RHA derived 30 wt.% silica-containing sol is used as a binder system for high alumina refractory castable. The sintering of castable is performed at 1400°C, 1500°C, and 1550°C. The different physico-mechanical characterizations and blast furnace slag (BFS) corrosion test at 1500°C are comprehensively investigated with the prepared castables. 1550°C fired and total 5 wt.% silica (2 wt.% dry sol and 3 wt.% from sol) containing sample shows hot modulus of rupture (HMoR) around 14 MPa at 1400°C and retains thermal shock resistance (1200°C to room temperature) after 10^{th} cycles around 57 % of its initial strength value.

The synthetic wollastonite is fabricated using waste chicken ES and RHA through an economical solid-state route. The physico-mechanical and dielectric properties of para- and pseudo-wollastonite are comparatively investigated. The obtained results show low dielectric constant (ε') of about 4.5 to 6, losses ($\tan\delta$) of about 0.0026 to 0.00361, the resistivity of around 6 to 9×10^8 (Ω-cm) at 100 kHz, and a bending strength of about 26 to 67 MPa.

Ceramic tiles are fabricated using wastes derived wollastonite and river silt (Kosi river, India) as ingredients in the place of feldspar and quartz, respectively. The samples are prepared by the semi-dry process, and sintering is performed at different temperatures, i.e., 1000°C, 1100°C, and 1130°C in air atmosphere. Fully replaced quartz and feldspar by silt and wollastonite containing sample, sintered at 1100°C fulfills the ISO standard and offers bending strength ~48.82 MPa and water absorption ~0.36 wt.%.

The multi-phase ceramic powder (MCP) is formulated using a 1:1 weight ratio of heat-treated seashell and FA as ingredients and calcined at 1100°C. The MCP is used with unground rice husk ash (URHA), rice husk (RH), and ordinary portland cement (OPC) for the fabrication of sustainable ceramic board (CB) through a simple room temperature curing method. The wastes derived CB exhibits good properties than a standard internationally calcium silicate board's technical data, i.e., low density (<1000 kg/m^3), good bending strength (>6 MPa), and low thermal conductivity (<0.22 W/m·K).

Insulation refractories are fabricated using FA, RH, RHA, and fired refractory grog as raw materials. Various samples are prepared with different compositions based upon partial and fully replacement of clay by FA. Rice husk is used as an additive to produce the pores in the matrix. The results show that the use of waste materials decreases the thermal conductivity and bulk density of the insulation refractory. 800°C fired and 100 wt.% the waste incorporated sample is shown cold crushing strength ~15 MPa and thermal conductivity ~0.942 W/m·K at 600°C.

The outcome of this investigation suggests that these waste materials may lead to be used as potential materials for the production of different ceramics. RHA can be found as an interesting substitute for the convention silica sources, and ES & seashell as an alternate of calcium sources for the making of ceramics. The technology from this work may expect to commercially feasible for the industrial production of nano-silica, silica-sol, wollastonite, ceramic board, and insulation refractory ceramics.

Keywords:

Waste; Rice husk ash; Nano silica; Foam; Fly ash; Castable; Ceramic board; Refractory.