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Review article

Cenospheres: A review

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HIGHLIGHTS

- Review about cenospheres including theories about formation and structure.
- Different separation techniques to remove cenospheres from fly ash are described.
- Introduction of potential application in construction industry.
- Summary of the most recent research.

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ABSTRACT

Cenospheres are one of the most value added fractions of coal fly ash. They have a hollow spherical structure and can be applied in many industrial applications, due to their superior properties; such as low bulk density, high thermal resistance, high workability and high strength. This review, focuses on the formation of cenospheres, their characterisation, including the chemical composition, their recovery from fly ash and the influence on mechanical properties when mixed with different materials.

Contents

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1. Introduction

Coal is widely used to generate electricity throughout the world. About 41% of global electricity is produced in thermal power plants fuelled by coal and an increase to about 44% is expected by 2030 [1]. After combustion of coal, fly ash is produced as a waste product in large quantities. It is estimated that approximately 750 million tonnes are produced annually worldwide, with a growing rate. Due to the fact that landfill is relative expensive, many value added applications have been suggested, as shown in Fig. 1.

Although Fig. 1 points out many areas for the re-use of fly ash, the utilization is limited to about 68 wt% in China, 47 wt% in Europe, 39 wt% in the US, 15 wt% in Russia, 10 wt% in Australia and generally 25 wt% worldwide. This means significant amounts remain, which currently are disposed of in landfill or ash lagoons [2–8]. To increase the re-use of coal fly ash several separation methods have been developed to segregate value-added components, such as aluminosilicates, magnetites, cenospheres and unburned carbon [9]. From all mentioned components, cenospheres are one of the most important value-added material found in fly ash. This is due to their exclusive properties, such as: light weight; high compressive strength; superior insulation; enhanced flow characteristics; less water absorption; chemical inertness and good thermal resistance. These properties make them suitable to a wide range of industrial applications [10]. Therefore, this review will focus on cenospheres, explain the formation process, characterizations, separation methods and potential applications.

1.1. Cenospheres

The word cenosphere is a combination of two Greek words: kenos (hollow) and sphaira (sphere) which describes the major characteristic of this material [11]. Cenospheres are spherical particles with a hollow center. Their concentration in fly ash varies over a wide range, from 0.01 to 4.80 wt%; but in most cases limits between 0.3 and 1.5 wt% [12–14]. The formation of cenospheres during combustion depends on the total mineral content of the feed coal and the combustion process [15,16].

1.2. Potential applications

The spherical shape of cenospheres creates a low surface area to volume ratio, which requires less resin, binder and water to wet out the surface. This property makes it a demandable filler to polymers and various polymeric composites such as: polyurethane composites [17]; polyester composites [18]; functionally gradient materials [19]; syntactic polymer foam [20]; high impact strength nylon composite [21]. Furthermore, by coating cenospheres with copper and incorporation in organic polymers, it is possible to change the polymers electric properties from an isolator to a conductive material [22,23].

The shells of cenospheres are made primarily of aluminosilicate phases, that are thermally stable and can be used to make high temperature resistant aluminum syntactic foam, with a high energy absorption, damping properties suitable for making automotive brake rotors and differential covers [24]. Apart from mechanical and thermal properties, aluminum syntactic foam shows an enhanced electromagnetic shielding compared with the basic matrix alloy [25]. Similarly, nickel coated cenospheres shows a potential for shielding and microwave absorption applications [26].

As a mullite rich material, cenospheres have potential in applications such as mullite-coated diesel engine components, refractories, heat exchangers, industrial furnaces for glass re-melting, steel soaking and aluminum reclamation [1,27]. Next to these, cenospheres ceramic foam coatings are particularly promising because of their high thermal stability, low thermal expansion, high creep resistance in highly oxidative and corrosive environments, high resistance to crack propagation and high thermal shock resistance.

For construction applications, cenospheres can be used as an additive to make light weight cements with reduced water release [28–30]. Cenospheres spherical and hollow morphology, chemical

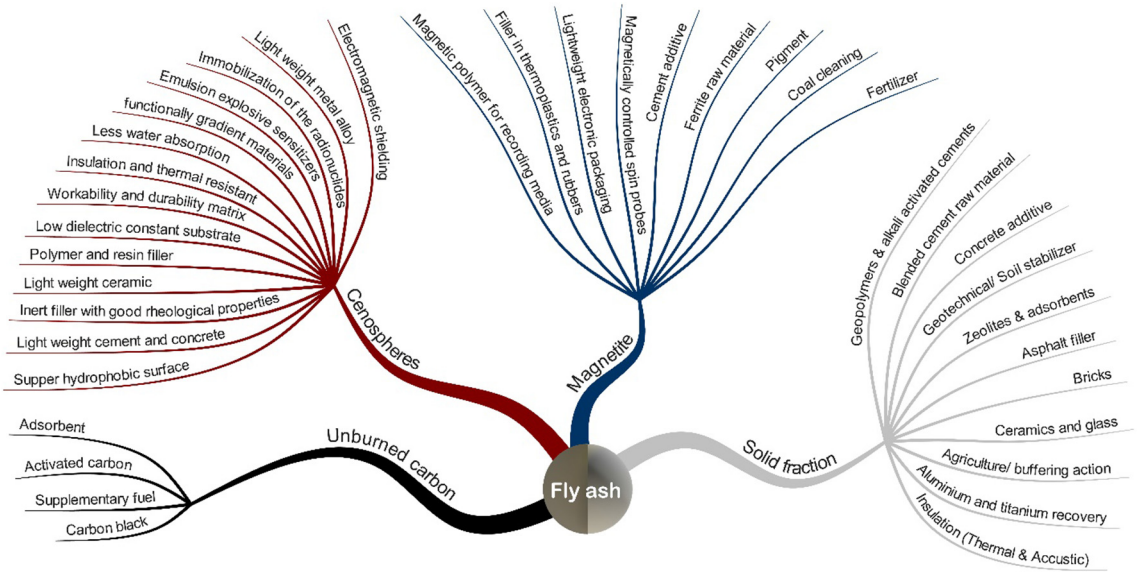

Fig. 1. Different component of fly ash and their potential applications.