"invention" will refer to subject matter recited in one or more, but not necessarily all, of the claims. Each of the inventions is described in greater detail below, including specific aspects, versions and examples, but the inventions are not limited to these aspects, versions or examples, which are included to enable a person having ordinary skill in the art to make and use the inventions when the information in this patent is combined with available information and technology.

[0013] Various terms as used herein. To the extent a term used in a claim is not defined herein, it should be given the broadest definition persons in the pertinent art have given that term as reflected in printed publications and issued patents at the time of filing. Further, unless otherwise specified, all compounds described herein may be substituted or unsubstituted and the listing of compounds includes derivatives thereof.

[0014] Further, various ranges and/or numerical limitations may be expressly stated below. It should be recognized that unless stated otherwise, it is intended that endpoints are to be interchangeable and any ranges shall include iterative ranges falling within the expressly stated ranges or limitations.

[0015] While approaches for increasing the service life of concrete structures in the prior art have focused on producing a more impermeable matrix by reductions in water-to-cementitious materials ratio and the addition of fine particles such as silica fume, in an approach of an aspect of the present invention, focus is placed on the physical properties of the pore solution in the concrete matrix through which diffusive transport of deleterious elements from an external environment occurs. Examples of such deleterious ions include chlorides, sulfates, and other ions or deleterious species known in the art that may attack the concrete matrix and/or structural support materials therein. Examples of such environments having elevated levels of deleterious species include roads, bridges, and costal structures.

[0016] Aspects of the invention generally include concrete having an extended service life and methods of making the same. Nano-sized organic water soluble diffusive transport modifying materials may be used to decrease ion diffusion coefficients in a pore solution within pores in the cured concrete. Cured concrete may have in the range of about 5% to 15% pore volume, and even more, and may have a pore solution trapped within the pores. A reduction in the diffusivity of deleterious ions such as chloride and sulfate ions within the pore solution may increase the service life of the concrete.

[0017] A reduction of the ion diffusion coefficients within the pore solution may reduce the rate of concrete material degradation by impeding the diffusion of ions such as sulfates that may react with the mineral phases within the concrete composite matrix or aggregates and thereby degrade the concrete element. Additionally, reduction of the ion diffusion coefficients within the pore solution may also reduce degradation of the concrete material by impeding the diffusion of ions such as chlorides that may degrade any structural steel that may be encased within structural concrete. The selection of the organic water soluble diffusive transport modifying material(s) may be based on effects on electrical conductivity of an ionic solution, size or molecular weight, and/or effects on pore solution viscosity.

[0018] Typically, hardened concrete can have a substantial amount of pore volume therein. The pore volume may be about 5% to 15%, or even up to 30%, for example. Within the individual pores, an amount of water may be trapped therein, forming a pore solution. The pore solution contains ions dissolved from the cementing material and the pores typically provide a pathway for the ingress of deleterious elements from the external environment. In one or more aspects of the present invention, the diffusivity properties of the pore solution may be lowered, resulting in a concrete material having decreased diffusion rates of the deleterious elements within the concrete matrix.

[0019] In one or more aspects of the present invention, at least one organic nano-sized water soluble diffusive transport modifier is added to the water, aggregate(s), cementing agent (s), and other optional additives making up a wet concrete mixture. The diffusive transport modifier(s) may be one or more organic water soluble material(s) which has a substantial portion remaining in the pore solution within the matrix of the concrete after hydration.

[0020] An understanding of the selection criteria of the diffusive transport modifier(s) to reduce the ion mobilities (diffusion) within a pore solution is gained by considering the motion of the ions at the molecular level. The motion of an individual ion in the pore solution is characterized by the particle mobility μ, which is the ratio of the particle velocity to the force on the particle. The Einstein relation expresses the self-diffusion coefficient D_0 of an ion as a function of its mobility μ as:

$$D_0=\mu k_B T$$

[0021] The quantities k_B and T are the Boltzmann constant and the thermodynamic temperature, respectively, and the product has units of energy.

[0022] The self-diffusion coefficient may be modified by altering the solvent properties. For example, for a spherical particle having radius r in a fluid (composed of much smaller particles acting as a solvent) having viscosity η_0, the self-diffusion coefficient may be represented by the Stokes-Einstein relation as:

$$D_0=k_B T/(6\pi\eta_0 r)$$

[0023] This relationship shows that the self-diffusion of an ion may be changed by changing the viscosity of the solvent. This relationship between the self-diffusion coefficient and the viscosity suggests that changes in the solution viscosity η may change the self-diffusion coefficient. This relationship may be expressed as:

$$D/D_0=\eta_0/\eta$$

[0024] Therefore, the self diffusion coefficient is shown to be inversely proportional to the solvent viscosity. For example, if the fluid viscosity η was increased to be twice that of its original value, η_0, the corresponding diffusion coefficient D, may decrease by a factor of two relative to its original value D_0. Thus, the service life of the concrete may be increased by increasing the viscosity of the pore solution since a substantial amount of the diffusion is through the pore solution of the concrete. However, this effect may only be valid where the Stokes equation applies: diffusing particles in a fluid composed of smaller (or similar size) particles. A limitation on size or molecular weight of the diffusive transport modifier is shown to be a boundary between changing the bulk viscosity and changing the solvent viscosity. For the diffusing ions relevant to typical concrete degradation mechanisms, it is shown herein that this boundary may be at a molecular weight of about 1,000 g/mol.