EFFECT OF TEMPERATURE ON THE SUSTAINABILITY OF ECO-ENGINEERED CEMENTITIOUS COMPOSITES: CURING, EXTREME CONDITIONS AND SERVICE LIFE

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With over 30 billion tons of global annual production, concrete is the most used construction material in the world. Its manufacturing is associated with a strong environmental impact due to the high natural resources' consumption, energy consumption, and a large generation of wastes and pollutants with significant global consequences. There are many different approaches to reduce the environmental impact of cementitious materials. Two examples are: (i) the use of recycled aggregate (RA) such as recycled concrete aggregate (RCA) and recycled plastics, or supplementary cementitious materials (SCMs) such as biomass ashes to reduce the use of natural aggregates and cement, respectively, and (ii) using nano-additives (for instance, nano-TiO_2) to enhance material's performance and to provide the material new properties that may have a positive proactive effect during its service life (i.e., photocatalytic properties that may reduce different pollutants concentrations from the environment). These approaches have been widely studied in standard conditions. However, boundary conditions such as temperature or moisture can be critical factors that directly or indirectly affect the effect of these approaches on the sustainability of cementitious composites in all stages of their life, from curing to service conditions.

It is known that curing temperature influences the effect of using recycled materials (such as RCA or SCMs) on the mechanical properties of cementitious materials. However, there were no studies concerning the influence of curing temperature on the nano-TiO_2 addition effect on mechanical properties of cementitious composites. A potential change will affect composites' sustainability; if curing temperature influences the effect of nano-TiO_2 on strength, the cement content needed to achieve a given performance will variate. This study concluded that curing temperature is a key factor that changes the effect of TiO_2 nanoparticles on mechanical properties and pore structure of Portland cement mortars; the lower the curing temperature, the higher the positive effect of TiO_2 on compressive strength. Besides the use of nano-TiO_2, the substitution of NA with RCA might significantly benefit the sustainability of cementitious composites. However, the use of RCA may lead to a reduction in strength. On the other hand, the addition of nano-TiO_2 mixtures containing RCA might offset this reduction in strength. Nevertheless, studying their effects on the composites' performance under extreme conditions is critical to assess the actual environmental impact since durability is one of the main pillars of cementitious materials sustainability. This study concluded that even though RCA may be beneficial to increase sustainability aspects in terms of net waste generation and natural abiotic depletion, its potential negative effects on high-temperature resistance should be considered to not lead to structural problems during its lifetime, especially if used in combination with nano-TiO_2. The addition of low percentages of nano-TiO_2 has a negative effect on the high-temperature resistance of mortar containing 100% RCA. Differences in thermal properties between old aggregate, old cement paste, and new cement paste with nano-TiO_2 may induce internal stresses at high temperatures that can produce a failure at lower strength due to the weaker interfacial transition zone (ITZ) between the stronger new cement paste (with nano-TiO_2) and the old cement paste. To the same extent, it is important to understand how extreme temperatures impact the effect of other recycled materials in cementitious composite performance. This study found that recycled polypropylene (re-PP) fibers may mitigate the strength loss caused by high-temperature exposure, enhance the residual flexural strength, and increase the energy absorption capability. The changes in the fiber-matrix ITZ after cooling observed through an optical microscope suggested that the mechanical improvements are related to an enhancement of the fiber-matrix ITZ after high-temperature exposure and cooling.

The next part of the dissertation focused on studying the thermal conductivity susceptibility to ambient conditions variation and how RCA substitution can affect this susceptibility. Understanding the effect of RCA on the thermal conductivity of cementitious composites would be crucial to assess their effects on the environmental impact during service life as part of a building component. Results showed that the higher percentage of porosity (due to RCA utilization) increases the susceptibility of thermal conductivity to moisture. Thus, actual moisture content and temperature should be considered when assessing the effect of RCA on thermal conductivity and its influence on sustainability in terms of energy savings when used as part of building envelops.

Finally, the last part of this dissertation focused on assessing the impact of curing temperature on the sustainability of sugarcane bagasse ash (SCBA) as a partial replacement of cement in mortars. An experimental campaign was performed to evaluate the effect of partial replacement of cement with SCBA on compressive strength as a function of curing temperature. Hence, a life cycle assessment (LCA) was performed from the extraction of the raw materials to the material production part of the life cycle, using as a functional unit 1 m^3 of mortar with the same compressive strength as the reference mixture (plain Portland cement mortar without SCBA) cured at the same temperature. Results showed that a replacement of 97 kg of cement by SCBA (per m^3 of mortar) may produce a reduction of the environmental impacts two times higher when the curing temperature was 45°C than when the temperature was 21°C. Results clearly indicate that the sustainability of SCBA utilization as a partial replacement for cement will be higher when mortar is poured in hot regions or during days with higher temperatures. Therefore, external curing temperature is an important factor that should be considered when assessing the sustainability of cementitious composites containing sugarcane biomass ashes.