# APPROXIMATION BY THE FINITE ELEMENT METHOD TO THE PREFERENTIAL CHLORIDE DIFFUSION THROUGH INTERFACIAL TRANSITION ZONE IN CONCRETE

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***Abstract*— Chloride diffusion in concrete is a main aspect of reinforced concrete durability. It defines the time required for reinforcement corrosion in marine structures. Concrete porosity is one of the main concerns involved in the process of chloride ingress from the environment into concrete. However, concrete can hardly be considered homogeneous in the meso-level. Natural coarse aggregates are usually less porous than the cementitious matrix, whereas interfacial zones between aggregates and the matrix are the most porous phase in concrete. This aspect is difficult to be experimentally studied, as very small samples need to be collected and analyzed. As an approach, the diffusion process can be simulated with the Finite Element Method (FEM). In this paper, chloride diffusion into concrete is simulated with a 2D FEM model, distinguishing three phases with different porosities in the material. Interfacial zone is identified as preferential path for chloride ingress. The study reveals a significant influence of particle inclusion on the chloride diffusion into concrete, and the effect of the particle shape.**

***Keywords*— Chloride, Concrete, Diffusion, Interfacial Transition Zone, FEM.**

## I. INTRODUCTION

Reinforced concrete plays a key role in the construction industry. It is the most used material for structural purposes. Durability is one of its advantages over other materials, especially metallic materials. However, some durability issues may appear with time in reinforced concrete. Chloride is present in the marine environment, and it ingress into concrete by absorption, permeability and diffusion. When the threshold chloride content is reached at the reinforcement depth level, steel depassivates and corrodes. Cover concrete eventually cracks due to the pressure of expanding oxides. Then, the process speeds up with steel more exposed to the environment. Chloride ingress into concrete is usually associated with diffusion through concrete pore structure. This is a simplification of the multimechanistic process.

Concrete is basically constituted by fine aggregate (sand), coarse aggregate (stone), Portland cement, and water. Hardened concrete is an artificial porous rock. A fraction of mixing water reacts with cement in the hardening process, whereas pores are due to evaporation of non-reacting water. In the meso-level, hardened concrete may be divided in three phases: aggregate, interfacial transition zone (ITZ), and matrix. Each one has a certain porosity level. The properties of aggregates are those of the rock of which they are constituted. ITZ and matrix properties depend on the proportions of constituents in concrete, curing conditions, age, admixtures, cement content, type of aggregates, and others. ITZ in concrete is originated, to a large extent, by the formation of water-filled spaces around aggregate particles in the fresh mix. ITZ is thus characterized by an increased porosity relative to the matrix phase and most of the rocks commonly used as aggregate. Therefore, it is the weakest zone for the transport of aggressive agents.

In general, concrete is treated as a homogeneous medium as regards chloride ingress (Andrade, 1993; Martin-Perez *et al.*, 2001; Poulsen and Mejlbro, 2006) and characterized by a single diffusion coefficient. However, diffusion cannot be homogeneous in concrete when considered as a multiphased material.

The influence of ITZ on chloride diffusion into concrete may be affected by geometrical parameters such as the particle shape of aggregates. Proximity is the main factor that defines the type of aggregate used in concrete making. Some very common types are crushed stone (e.g., granite, basalt, sandstone), and rounded gravel (from a river or seashore). The respective angular or rounded particle shapes define two cases for the observation of chloride diffusion in three-phased concrete.

Natural aggregates usually have a much lower porosity than that of the matrix or ITZ. Therefore, transport through the aggregate phase is generally negligible in concrete. Assuming this simplification, coarse aggregate particles act as obstacles for the chloride ingress process. However, these obstacles are surrounded by the most porous phase in concrete, ITZ, and transport is favored on the aggregate boundaries.

Aggregate particles in the matrix have two effects. The addition of solid obstacles increases tortuosity, and chloride ions must move around these particles. On the other hand, the formation of ITZ facilitates ion mobility. The relative importance of these two opposite effects will define the overall transport affectation by the aggregate inclusion. In this analysis, parameters such as aggregate absorption, maximum aggregate size, flatness and elongation, emerge as important issues.

Preferential diffusion through ITZ in concrete is hardly demonstrable by experimental work. Very small samples need to be collected and analyzed to describe chloride transport through the meso-structure of concrete. Here, the Finite Element Method (FEM) is noticed as a useful tool to approximate the phenomenon.