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Simple tools for fiber orientation prediction in industrial practice

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ABSTRACT

In this paper, the two origins of the preferred orientation of fibers are first reviewed. We then propose a definition of what to call an oriented fiber from a practical point of view in the cementitious material field. Considering typical industrial flows and materials, we identify the dominant phenomena and orientation characteristic time involved in the fiber orientation process in the construction industry. We show that shear induced fiber orientation is almost instantaneous at the time scale of a typical casting process. We moreover emphasize the fact that shear induced orientation is far stronger in the case of fluid materials such as self compacting concretes. The proposed approach is validated on experimental measurements in a simple channel flow. Finally, a semi-empirical relation allowing for the prediction of the average orientation factor in a section as a function of the rheological behavior, the length of the fibers and the geometry of the element to be cast is proposed.

1. Introduction

Fibers have a very positive influence on the mechanical properties of cementitious materials in the hardened state. This influence depends primarily on the fibers (shape, constitutive material, volume fraction) but also on the casting process. Indeed, contrary to traditional aggregates, flow, in the case of fiber reinforced materials, can induce a preferred orientation of the fibers which strongly modify both fresh and hardened material properties [1–4].

Fiber efficiency has been found to decrease from 100% for totally aligned fibers down to 30% for fibers randomly oriented [5]. The existence of an optimum inclination maximizing fiber contribution at each stage of the crack bridging process [2] was moreover demonstrated from pull out studies of a single fiber. Considering the economical cost of adding fibers to cementitious materials, these two experimental facts show how useful fiber orientation prediction tools could be for industrial practice.

Orientation of fibers is however a very complex phenomenon. It finds its origins in both wall effects which depend on the geometry of the element to be cast [6] and shear induced orientation which depends on both rheological behavior of the material, geometry of the element to be cast and casting process. The latter was first described by Jeffery [7] in 1922 in the case of an ellipsoid immersed in a purely Newtonian fluid. This problem has been and is still the subject of numerous papers in literature as Jeffery's initial solution only applied to dilute systems whereas industry has a strong use of semi-dilute, semi-concentrated or even concentrated systems [8–18]. Literature provides fewer studies in the case of fibers suspended in non Newtonian fluids such as concrete [1,19–22]. Most of the above studies make a strong use of some so-called “orientation tensors”. However, in civil engineering, a scalar called “orientation factor” is preferentially used to describe the orientation state of the material in a given section [6,23–28]. Although numerous methods described in literature based either on visual counting, image analysis or non destructive testing allows for the measurement of this orientation factor [23–28], no simple method exists for its prediction even approximate as a function of geometry of the element to be cast, casting process and fresh material properties.

In this paper, the two origins of the preferred orientation of fibers are first reviewed. We then propose a definition of what to call an oriented fiber from a practical point of view in the cementitious material field. Considering typical industrial flows and materials, we identify the dominant phenomena and orientation characteristic time involved in the fiber orientation process in the construction industry. The proposed approach is validated on experimental measurements in a simple channel flow. Finally, a semi-empirical relation allowing for the prediction of the average orientation factor in a section as a function of the rheological behavior, the length of the fiber and the geometry of the element to be cast is proposed.

2. Fiber orientation: theoretical frame

2.1. The two origins of anisotropy

There are two reasons why fibers in a suspension adopt a preferred orientation. The first one finds its origin in the torque exerted by the suspending fluid on the fiber. In a flow dominated by shear stresses, the torque exerted on the fiber reaches a minimum when the fiber is parallel to the flow direction. This position is however unstable and, as

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