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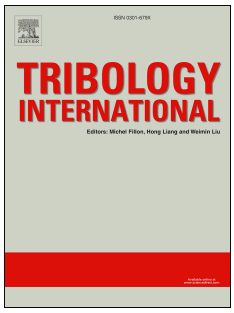

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ACCEPTED MANUSCRIPT

Combined experimental and numerical simulation of abrasive wear and its application to a tillage machine component

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Abstract

Abrasive wear of key components is a critical process limiting the lifetime of machinery for mining or farming. However, materials and process parameters are mostly based on empirical data since the underlying wear mechanisms in the field are not well known. In order to assess and predict the effects of abrasive wear on typical tillage machine components, the authors developed a combined experimental and numerical simulation procedure based on a time- and space-resolved version of the Archard wear equation. The applicability of the aforementioned procedure is demonstrated on a tooth of a circular harrow. The simulated worn geometry is in good agreement with the real geometry of a tooth worn in a soil bin.

Keywords: Wear, Simulation, Finite-Element Method, Boundary Element Method

1. Introduction

The agricultural industry, and in particular machinery for tillage, is highly susceptible to the adverse effects of abrasive wear. It has been estimated that as many as 40% of component replacements are due to it [1]. Various technologies and materials have been developed to combat abrasive wear in machinery for tillage. Nevertheless, the materials and process parameters are mostly based on empirical data since the underlying wear mechanisms in the field are not well known.

For more than a century considerable effort has been invested in understanding the physics behind tillage operations [2]. Several phenomenological analytical models have been developed to predict draft forces on tillage tools, with varying level of success (see for example References [3–6]). Nevertheless, their applicability is constrained to the tool geometries for which they were derived. With the increase in computational power during the last decades, the application of numerical models applying the finite element method (FEM) has been explored (see for instance References [7–11]). This method is more general than the analytical schemes since it can treat tools of arbitrary geometry. The main difficulty in applying it stems from the need for a description of large-scale deformation of soil, which is required to properly model the movement of soil around and ahead of the tool. Because of the limitations of constitutive relations, predictions of these analyses have not been able to address tillage dynamics with high shear rates [2, 12]. The discrete element method (DEM) has emerged as a promising alternative numerical approach to model the soil-tool interaction [13–15]. The forces on tillage tools calculated with this method have shown good correlation with experimental results. However, the absence of a robust method to determine the parameters needed by the model hinders its widespread use. As noted in previous studies, soil acts as a solid prior to failure; however, once failure has been reached it acts more like a fluid [16]. These observations have motivated the consideration of the Bingham plastic model to describe the visco-plastic nature of soil [17], an idea which has been implemented in computational fluid dynamics (CFD) models [2, 18–20]. This approach has proven advantageous over other numerical methods since it only requires modeling of the soil around the tool, and the parameters needed to characterize the soil are reduced to three quantities (density, yield strength, and viscosity). These qualities make the CFD-approach suitable as an engineering tool for optimization of tillage machinery. In the application of this model it must be nevertheless considered that the tool has no momentum because it remains stationary while the soil flows around it. A discussion on the implications of this effect can be found in Reference [2].

In spite of the availability and progress of various methods for evaluating the forces acting on tillage tools and other machinery components, the framework needed to link these forces to the corresponding observed wear has yet to be established. For this framework to be useful in an optimization process, it should allow evaluation of

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