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FINITE ELEMENT SIMULATION OF THE FULL STANCE-PHASE IN THE DESIGN PROCESS OF A 3D-PRINTED COMPOSITE FOOT PROSTHESIS

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ABSTRACT

Additive manufacturing (AM) of composites is becoming an advantageous technology to utilize in prosthetic applications [1]. Especially through the employment of continuous fiber reinforcement, the potential of AM in producing prostheses to withstand high loads could be demonstrated [2]. Moreover, the rapidity and versatility offered by AM enable high customizability, which is an essential feature for prosthetic applications [1]. However, this creates the demand for simulation tools capable of characterizing the structural and biomechanical performance efficiently to aid the design process of customized prostheses. The demand for such tools is furtherly emphasized considering the increasing interest in gait performance monitoring using sensors integrated in 3D printed composites such as Fiber Bragg Grating (FBG) sensors [3].

Therefore, this work aims to establish a finite element simulation of the full stance-phase of the gait cycle through which the structural and biomechanical parameters of a prosthesis are assessed. The simulated stance-phase conditions were those of the rollover test of ISO 16955 [4], shown in Figure 1. A preliminary model of the set-up of this test was developed as shown in Figure 2 (a).

To grant a reliable simulation, the prostheses were modeled in detail taking into account the anisotropic behavior of the continuous fiber reinforcement and the explicit geometry of the infill. Due to modeling sagittal plane conditions only [4], 2D finite elements were considered so as to achieve an efficient simulation. The modeling approach was validated by comparing the stiffness behavior of a prosthesis model to its corresponding printed prototype at the main stages of the gait cycle (heel-strike, mid-stance, and toe-off).

Various parameters such as the contact center of pressure and displacements were obtained at each increment of the cycle simulated. This enabled the characterization of the roll-over shape and prosthesis stiffness throughout all gait cycle stages, which are significant outcomes in the assessment of the prosthesis gait performance [5]. Similarly, the strain was obtained as illustrated in Figure 2 (b), allowing the estimation of strain variation throughout the gait cycle at various spots of the prosthesis structure. This is to aid the plan of integrating FBG sensors at a later stage of the design process to achieve a smart prosthesis structure [6].

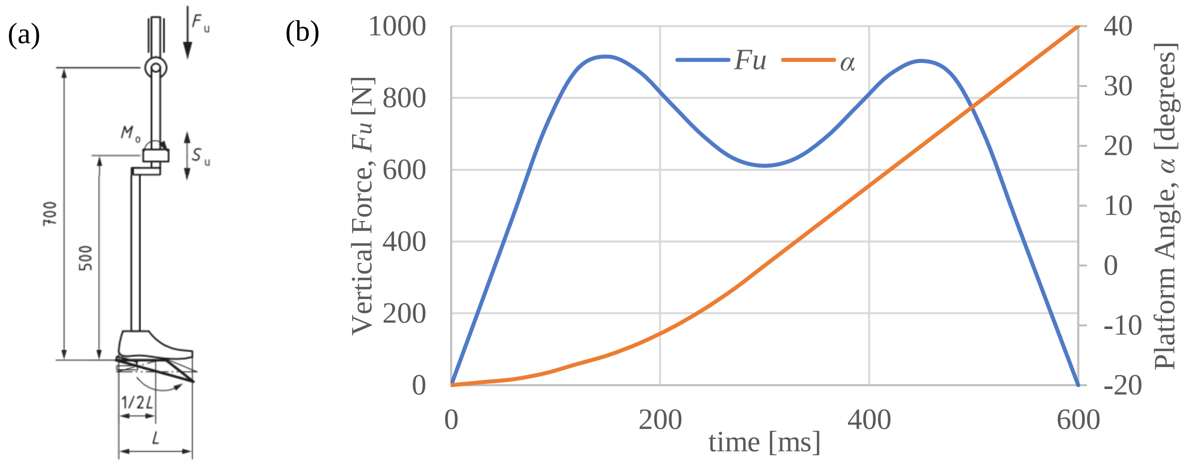

Figure 1: Description of the simulated rollover test of ISO 16955 [4], (a) schematic of the test set-up (dimensions in mm), (b) loading profile and foot platform rotation imposed.

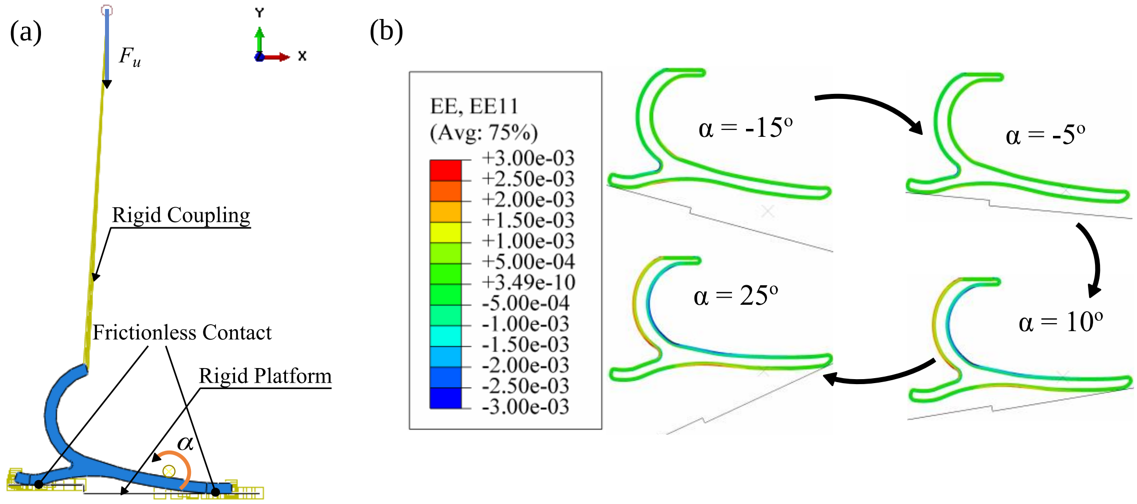

Figure 2: Illustration of the preliminary modeling and simulation performed for the rollover test, (a) test set-up model, (b) simulation of the strain variation at the outer layers of the prosthesis structure.

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