Computer Aided Engineering for the electropolishing process of orthopedic body implants

Electropolishing is a state-of-the-art surface finishing process for biomedical parts, devices, coronary stents, cardiovascular and orthopedic body implants. The electropolishing phenomenon is characterized by the elimination of surface roughness and by the absence of crystallographic and grain-boundary attack, resulting in the production of bright and glossy metal surfaces. Furthermore, due to its simplicity and ability to be used for polishing complex structures, electropolishing is a promising method for post-processing of the additively manufactured components. Nevertheless, the major challenge of the process is its effectiveness.

The effectiveness of the electropolishing process relies upon proper control of the current density distribution and the electrolyte refreshment over the substrate. In the case of poorly controlled current density distribution and insufficient electrolyte flow in proximity of the electropolished surface, an unacceptable roughness, pitting or even surface burning may occur. In addition, localized high current density areas will lead to an excessive local metal removal, thereby compromising the dimensional tolerances of the part.

To avoid this, Computer Aided Analysis (CAA) serves as fast and robust performance analysis of the electropolishing processes. Such a feasibility study enables to obtain the current density distribution and the associated metal removal rate distribution over the processed surfaces. As a result, detailed overview on the final quality of the product is provided well before it is physically electropolished. The obtained CAA simulation results of the *as-is* electropolishing process serve as a baseline for the following process improvement step, the so-called Computer Aided Engineering (CAE). The CAE stage focusses on the definition of an appropriate mitigation strategy (improved jig and tooling configuration), in order to achieve higher quality of the electropolished surfaces.

Elsyca has a long track record in the CAE projects that comprise computer simulations for the *as-is* electropolishing process performance at specific process conditions, and further process optimization, where a dedicated tooling concept must be developed. One of such electropolishing process analysis and improvement has been conducted on a tibial component of a Ti-based knee implant.

The aforementioned project was based upon in-house developed software platform, Elsyca EPOS (ElectroPOlishing Simulator), which simulates the distribution of the current density and metal removal rates. The current density distribution over a Ti-based tibial component has been simulated, whilst accounting for the CAD model of the tibial part, the configuration of the electropolishing cell, the process parameters and the electrolyte used. Among them, the analysis of the electrolytic solution is a crucial step since the electrochemical data serves as an essential input for the CAA study, permitting the accurate prediction of the metal removal rates.

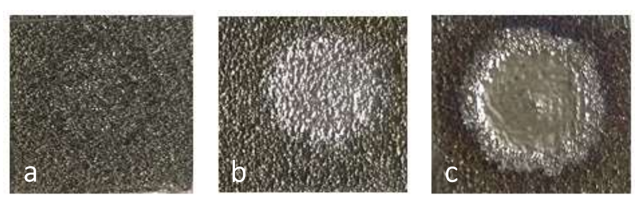

Fig. 1. Raw (a) and electropolished (b & c) Ti-based substrates (surface roughness influenced by different process parameters).

In addition to this, an unparalleled insight into the process is gained, which includes the operating window of the specific process conditions that

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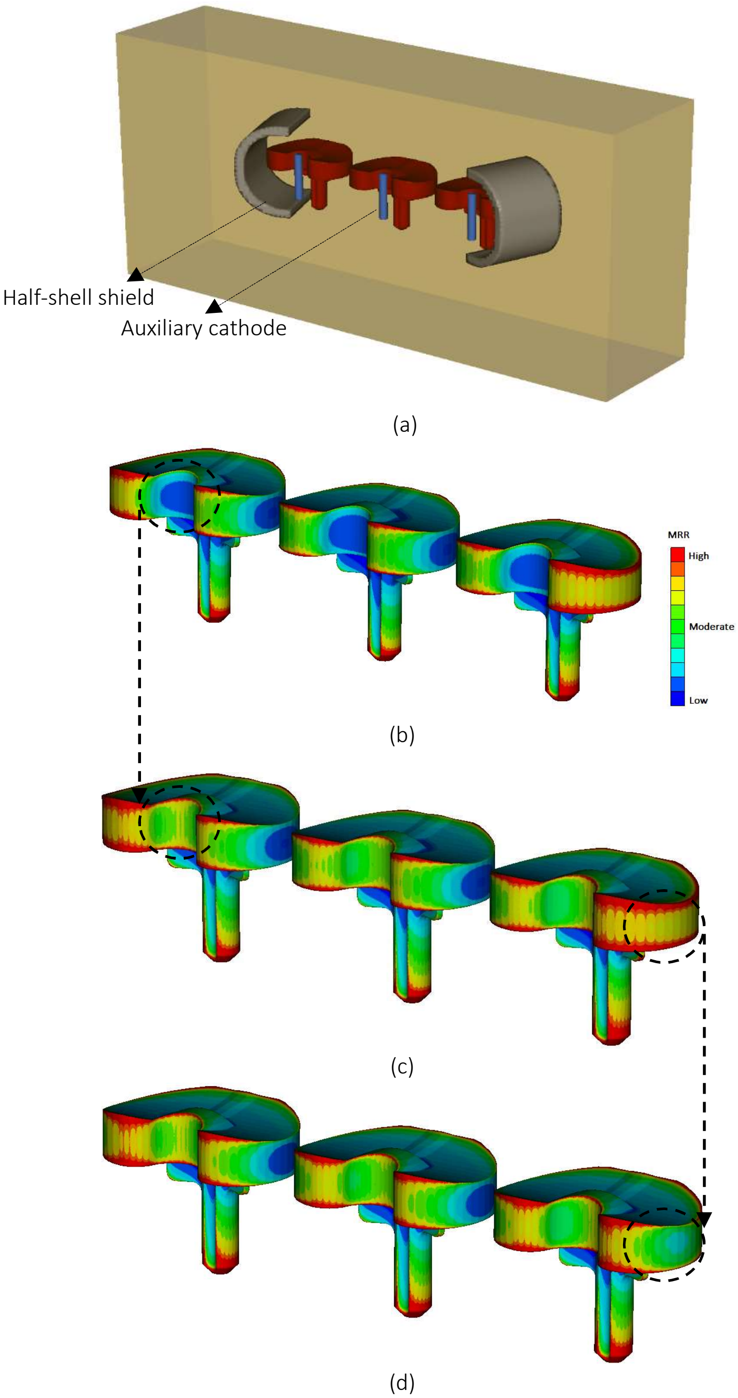

Fig. 2. Simulated metal removal rates (MRR) over a Ti-based tibial component: (a) electropolishing cell setup, (b) CAA – baseline simulation result without tooling, (c) CAE – effect of auxiliary cathodes, (d) CAE – effect of half-shell shields. Mapping meaning: red color represents a high MRR, green color – moderate MRR and blue color – low MRR.

ultimately ensure that the target surface quality is achieved, whilst obviating surface defects during further process optimization.

The technology uses Finite Element Analysis (FEA) in order to solve for the current density distribution over the parts and calculates the metal layer removal rates based on Faraday's law. The resulting simulated current density and metal layer removal distributions are represented by a color map, where different colors represent different values of current density and metal removal rates (MRR) over the specific part. The CAA of the Ti-based tibial component takes into account the electropolishing process setup with and without tooling structures (auxiliary cathodes and shields, Fig.2.(a)). The CAA, where no tooling was considered, revealed a risk of highly non-uniform MRR distribution (Fig.2.(b)). Taking the geometric complexity of the tibial component into account, both high (red color) and low (blue color) metal removal rate areas require implementation of an advanced mitigation strategy, developed in the CAE step. The CAE approach relies on the optimization of the process performance by developing dedicated tooling structures and by fine-tuning the process parameters. The use of dedicated tooling components allows one to either increase the metal removal rates on the surfaces subjected to low current densities or decrease the metal removal rates on the surfaces subjected to higher current densities. This is achieved by introducing either auxiliary cathodes (Fig.2.(c)) or shielding system (Fig.2.(d)), respectively.

The implementation of the tooling concept, together with further enhancements of the process parameters, permits significant improvements of the electropolishing process performance for all types of complex parts. Utilizing the aforementioned CAE approach permits one to perform such optimizations before the actual process can be run, assuring that final metal finish specifications are met.