Analysis of the porosity degree during laser-assisted cladding of bioactive glass on titanium substrates with highly refined grain structure

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Introduction

Titanium alloys, due to their exceptional mechanical properties and biocompatibility, are commonly used to produce medical implants nowadays. However, the presence of such elements as aluminium and vanadium can be harmful to human health. One of the possible solutions could be replacing the titanium alloys with commercially pure titanium (cpTi) with highly refined grain structure. One of the most promising methods in manufacturing medical implants with improved biological fixation is laser cladding in which bioactive glass coatings are imposed on metallic substrates. The aim of this work is to present a 3D numerical modelling of the above mentioned additive manufacturing process. The obtained model is able to predict the stress-strain and temperature distributions as well as porosity degree during the processing. Porosity affects the bioactivity of medical implants as it significantly improves their ability to bonding with host tissues.

Methods

A 3D sequentially coupled finite element (FE) model of laser cladding has been developed by applying element birth and death technique to calculate the transient temperature fields used in the stress analysis (fig. 1) [1]. In this work, the model has been extended for analysis of the porosity degree during cladding of bioactive material on titanium substrates with highly refined structure. The concentrated heat source from the laser beam moving along the metal surface has been represented by the Gaussian heat flux distribution. Due to lack of temperature dependent stress-strain curves data for the cpTi Grade 4 material with highly refined structure, its temperature dependent constitutive behaviour has been determined using the proposed algorithm.

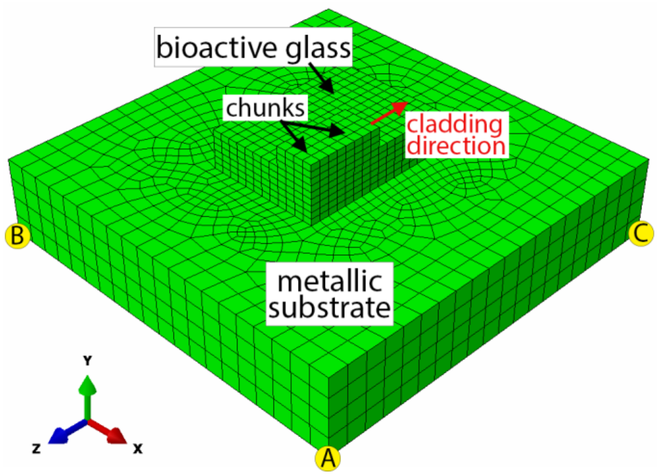

Fig. 1 FE model set-up showing the constrained metallic substrate with cladded layers of bioactive glass (letters A, B and C indicate constrained nodes).

Results and Discussion

Figure 2 shows the porosity distribution in bioactive material obtained after the laser cladding for various processing parameters. It can be seen, that the most favourable for obtaining high level of porosity is using higher speed laser without preheating of the substrate. The developed numerical model is able to support the optimal design of advanced multi-layered structural materials using the laser cladding technique.

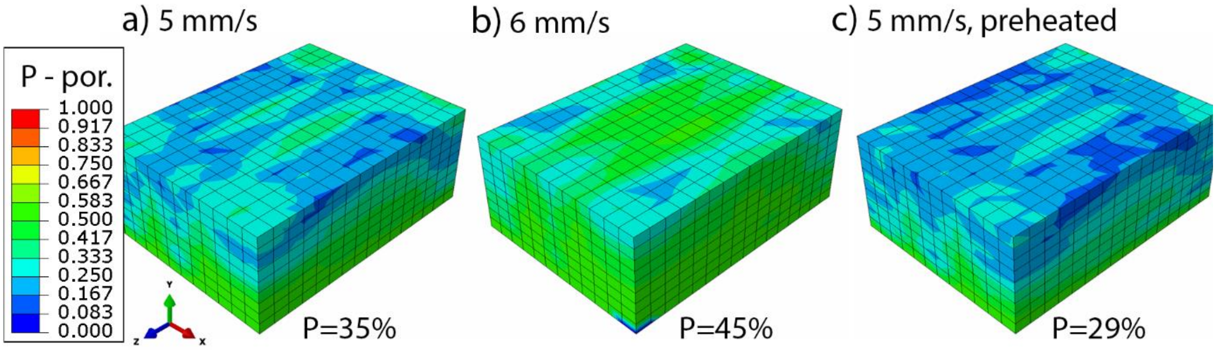

Fig. 2 The porosity distribution in bioactive glass predicted after the laser cladding with different parameters: a) 5 mm/s laser speed, b) 6 mm/s laser speed, c) 5 mm/s laser speed and substrate preheated to 300°C.

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References

[1] M. Krzyzanowski et al., J. Mech. Behav. Biomed. Mater., 59, 2016, 404–417.