多孔梯度生物陶瓷涂层的激光制备及生物活性研究

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摘要：为显著增加较大尺寸孔隙的数量和促进孔隙在涂层表面均匀地分布，本文采用在涂层粉末中添加造孔剂的方法，并通过激光熔覆技术制备了多孔梯度生物陶瓷涂层。利用金相显微镜(OM)、扫描电镜(SEM)、X 射线衍射仪(XRD)等测试手段，研究了造孔剂添加量对涂层组织结构及其生物性能的影响。结果表明，在激光功率 P = 1.8 kW、扫描速度 V = 240 mm/min、光斑直径 D = 4 mm 的工艺条件下，添加造孔剂$(NH_4)_2CO_3$制备的生物陶瓷涂层微观组织均匀、微裂纹少，涂层与基体结合良好，在 A = 2.5～10 wt.%造孔剂添加量范围内，涂层均含有 HA、*β*-TCP、TiO_2、$CaTiO_3$等相成分，与未加入造孔剂时涂层的物相一致。涂层孔隙的孔径分布范围为 1.5～10.5 μm 且最频分布孔径为 2.5 μm，而未加造孔剂的涂层的最频分布孔径为 1.5 μm，说明造孔剂的加入可显著改变孔隙的孔径大小，尤其是当 A = 2.5 wt.%时， 3.5 μm (35.70％)和 4.5 μm (23.73％) 的高频率分布表明，添加一定量的造孔剂有助于获得更多大尺寸的孔隙；SBF 浸泡试验和 MG63 细胞试验表明，当 A = 2.5 wt.%和 5 wt.%时，多孔梯度涂层均表现出良好的生物活性和生物相容性，该结果表明适量添加造孔剂所构筑的涂层孔隙结构有利于改善涂层的成骨性能。

关键词：激光熔覆；生物陶瓷涂层；造孔剂；孔隙尺寸；生物活性

Laser Preparation and Bioactivity Study of Porous Gradient Bioceramic Coatings

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Abstract: In order to increase the number of large-sized pores significantly and improve the distribution of uniform pores, a porous gradient bioceramic coating was fabricated by laser cladding with the method of adding pore-forming agent (PFA). Using OM, SEM, XRD and other characterization techniques, the influence of PFA quantity on the pore structure and its biological properties of the prepared bioceramic coating was studied. The results exhibit that under laser parameters P = 1.8 kW, V = 240 mm/min, and spot diameter D = 4 mm, the microstructure of the bioceramic coatings prepared by adding PFA to the coating powder is homogeneous and there are a few micro-cracks, and the interfaces between the coating and the substrate have good integration; $(NH_4)_2CO_3$ as PFA is added, its phase composition contains HA, β- TCP, TiO_2, $CaTiO_3$, *etc*., when A = 2.5～10 wt.% of the coating powder, which accord with the coating without PFA. The pore distribution range of the pore sizes is 1.5～10.5 μm and the most probable pore sizes is 2.5 μm, especially when A = 2.5 wt.%, the more large-sized pores can be obtained in accordance with 3.5 μm (35.70%) and 4.5 μm (23.73％) pore frequency, respectively. The most probable distribution shows that it is in favor of the bioceramic coating when the PFA additive content is appropriate to obtain more large-sized pores; The SBF immersion test and the MG63 osteoblasts cell activity test indicate that the A = 2.5~5 wt.% porous gradient coating has good bioactivity and cell biocompatibility. The results reveal that the pore structure characteristic of the coatings is beneficial for improving the osteogenic performance of the coatings.

Keywords: Pore size; Bioactivity; Laser cladding; Bioceramic coating; Pore-forming agent