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Metal/ceramic composites from freeze-cast preforms: domain structure and mechanical properties

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Short abstract

Innovative metal/ceramic composites produced by melt infiltration of ceramic performs prepared by a freeze-casting technique have been examined for the first time in this study. These composites exhibit a characteristic hierarchical structure: on a mesoscopic level, lamellar domains with sizes up to several millimetres are observed. The individual domains are composed of alternating ceramic and metallic lamellae with thickness in the range from 20 to 100 μm. The aim of the present study is to characterize the mechanical properties of the composite on different size scales. The elastic and plastic behaviour of individual domains were investigated by ultrasonic measurements and compression tests on miniature samples prepared from poly-domain material. The damage evolution during compressive loading was investigated by in-situ and ex-situ microscopic techniques. Study of processing induced thermal residual stress and strain distributions as well as the internal load transfer under external compressive loading was carried out using synchrotron X-ray energy dispersive diffraction. The highest stiffness is observed in the direction parallel to the preform freezing direction, the lowest in the direction perpendicular to it. The elastic properties of individual domains with different orientations were discussed in the light of a model based on 3D laminate structures with alternating layers of random thickness. Compressive mechanical tests of single domain samples showed that the composite is strong and brittle when loaded along directions parallel to the freezing direction. When loaded along other directions, the behavior is controlled by the soft metallic alloy. The plastic anisotropy is less pronounced than theoretical predictions for laminates, which is explained by the presence of bridges between the ceramic lamellae. Study of thermal residual stress and strain distributions showed that strongly fluctuating local phase specific residual stresses are present in the as-produced state which can be explained taking into account the thermal expansion mismatch of the alloy and the ceramic preform. Studies of internal load transfer under externally applied stresses show that the load transfer mechanism for loading along the freezing direction and along 0 ° to domain orientation are essentially similar. In the macroscopic elastic regime, the metallic and the ceramic phases share the load simultaneously. However, once the metallic phase starts to deform plastically, it transfers the load to the ceramic phase and acts only as a supporting material. The load transfer from the metallic phase to the ceramic phase is significant, but not complete. This may be attributed to the localized damage taking place within the ceramic lamellae and along the interface.