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Processing and Properties of High Quality Titanium Matrix Composites

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Unidirectional fiber reinforced titanium matrix composites (TMCs) are promising materials for highly loaded structural components such as utilized in jet engines. In the U.S., Europe and Germany the material is under consideration to realize new component design in the compressor. Major weight savings can be achieved by moving to a bladed ring ("bling") design [1]. However, the bling concept as well as further potential TMC applications as blades, shafts and actuators only justify the high cost of TMC components if the related pay-off appears to be significant. The benefit of local TMC reinforcements is highly influenced by the quality of the composite material.

Processing of high quality TMCs

Measures for the quality of the processing procedure are prior to testing the fiber distribution, the thickness of the reaction layers, and the extend of fiber and interface damage. With respect to applications, up-scaling is a critical step especially with respect to quality of local reinforcements. Magnetron sputtering, as used by DLR to pre-coat the fibers with a thick layer of matrix alloy, proved to be a method with minimum fiber damage during coating and allows low temperature/short term consolidation, due to a very fine equiaxed microstructure in the sputtered matrix (Fig.1). This results in thin reaction layers, which is beneficial with respect to mechanical properties. Furthermore the matrix coated fiber technique via magnetron sputtering excludes fiber touching and allows almost any matrix material to be applied. This is a significant advantage for the development of high temperature TMCs with orthorhombic matrices, containing large quantities of elements with strongly deviating vapor pressures.

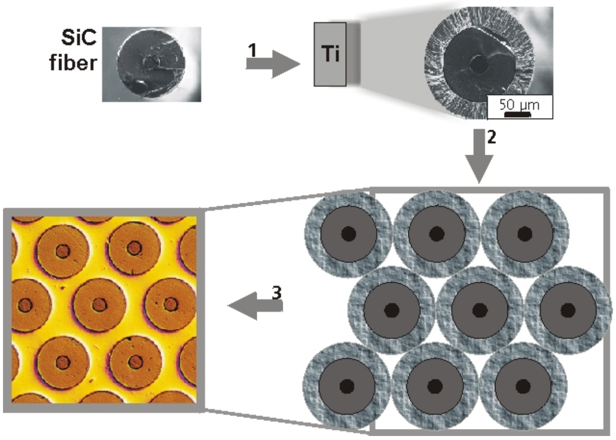


Fig.1 Processing of TMCs via fiber coating technique: (1) PVD coating of fibers with titanium matrix, (2) lay-up of coated fibers in a hexagonal close packed arrangement, (3) consolidation via hot isostatic pressing (HIP).

Orthorhombic titanium aluminides exhibit improved creep and oxidation resistance in comparison to conventional near-alpha titanium alloys. Thus orthorhombic TMCs are expected to extend the temperature capability of this material class significantly. During coating and consolidation the thickness of the final reaction zone is not only determined by the processing route, but also strongly influenced by the choice of the matrix alloy. Fig.2a shows the influence of consolidation temperature during HIPing on the reaction zone thickness. It is apparent, that the orthorhombic alloy Ti-22Al-25Nb leads to lower reaction rates than the near-alpha titanium alloy Timetal 834 or in particular the alpha-beta alloy Ti-6Al-4V. This enables very thin reaction zones in SCS-6/Ti-22Al-25Nb composites, down to 0.22 µm after full consolidation. After PVD coating and low temperature consolidation the matrix exhibits a very fine equiaxed microstructure. Such a microstructure is known for its low creep

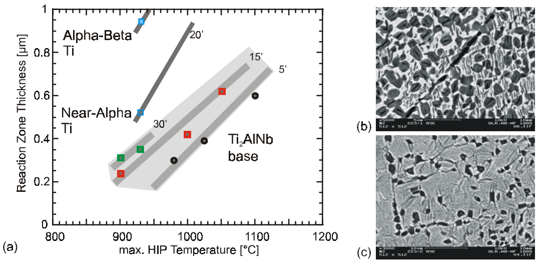
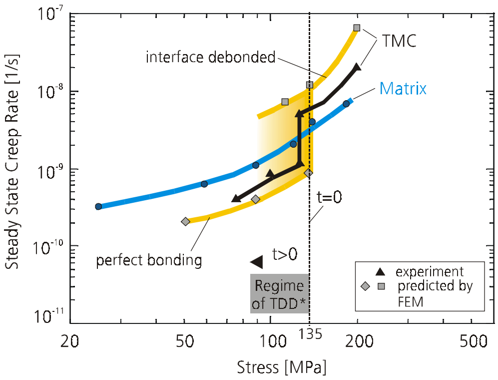


Fig. 2 (a) Influence of HIP conditions on reaction zone thickness for the Ti_2AlNb base alloy Ti-22Al-25Nb, Timetal 834 and Ti-6-4 as matrix; microstructure of Ti-22Al-25Nb matrix material after HIP at 900°C (b) and 1050°C (c).

resistance. The very low reaction rate of orthorhombic matrices make them the only titanium base matrix material available, which microstructure can be altered by post-consolidation heat treatment without unexcitable growth of the reaction zone. Investigations of monolithic Ti-22Al-25Nb material demonstrated significant improvement of creep resistance by modifying the microstructure from a duplex (Fig.2b) to a bimodal (Fig.2c) morphology [2].

Mechanical Properties of high quality TMCs

Although the axial properties of TMCs are clearly superior to existing materials, many applications will require a certain ratio of transverse to longitudinal properties. Transverse creep performance is predominantly determined by the bond strength of the interface between fiber and matrix and the creep resistance of the matrix. Depending of the state of the interface (bonded vs. debonded), the transverse creep resistance of TMCs exceeds the creep resistance of the matrix at low stresses, while at high stresses the transverse creep resistance of the composite falls below the unreinforced matrix material (Fig.3). An inhomogeneous fiber distribution reduces locally the distance between fibers, which increases the tangential shear stresses in comparison to the radial compressive stresses in the C-coating of involved fibers. Thus, the possibility that tangential shear stresses can break the bond before compressive stresses are relaxed is higher [3]. Crack initiation in transverse loaded specimens confirms this prediction. A homogeneous fiber distribution is therefore essential for TMCs to avoid premature failure during transverse loading.



TDD*: time dependent debonding

Fig. 3 Transverse creep data for SCS-6/Timetal 834 tested at 600° along with FE analyses data for fully debonded and fully bonded interfaces in the composite.

For applications of TMCs in next generation compressor rotors low cycle fatigue behavior is one of the most important criteria. Fig.4 shows the longitudinal fatigue behavior of TMC specimens (SiC/near-Alpha titanium) processed via the matrix coated fiber technique at room and elevated temperature [4]. It is obvious that the longitudinal low cycle fatigue behavior is significantly improved in comparison to the matrix material. Many low or room temperature data on high cycle fatigue of TMCs in literature exhibit values near or even below the endurance limit of the unreinforced matrix. However, high quality TMC material with fully encased fibers show high cycle fatigue strength up to 50% above the endurance limit of the matrix (Fig.4). FE-modelling demonstrates, that a homogeneous fiber distribution helps to reduce detrimental residual stress peaks. Therefore, a homogeneous fiber distribution combined with a very thin reaction layer and fully encased fibers delays fatigue crack initiation and improves propagation live of the material. At high temperatures stress relaxation in the matrix shifts a large portion of the applied load to the fatigue resistant ceramic fibers.

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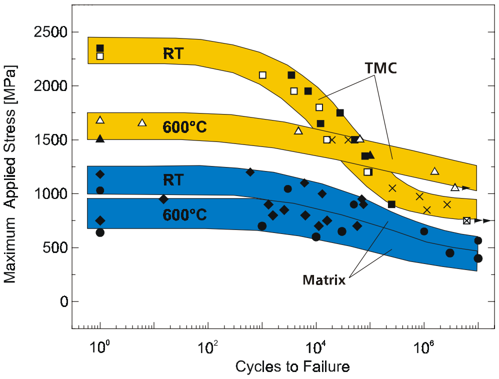

Fig.4: Longitudinal fatigue properties of SCS-6/Timetal 834 at RT and 600°C in comparison to the matrix material.