Ceramic composite materials and related production technologies for aerospace applications

The aerospace industries require lightweight materials with high performance, in terms of thermomechanical properties, hardness, resistance to erosion and/or corrosion as well as a high degree of reliability. Ceramic matrix composite materials have all these characteristics, and are the main candidates to substitute metals and monolithic ceramics for all high-end applications where performances, in term of weight and working temperature, cannot be achieved with materials traditionally employed. In particular, they overcome the lacks of the traditionally used materials, that is metal materials, whose main application limit is represented by operating temperatures that cannot exceed 1000°C, and the monolithic ceramics: the second phase of reinforcements modify the fracture behaviour from the typical brittle of monolithic ceramics to the so called pseudplastic of CMCs (fig. 1).

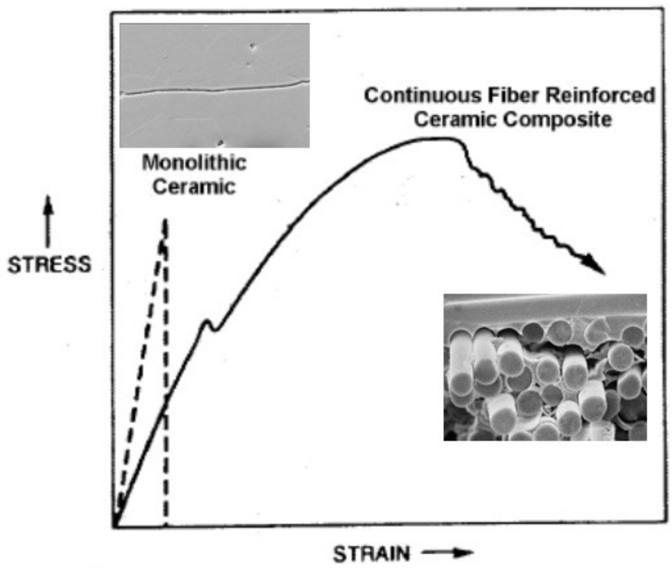

Fig. 1: brittle vs pseudoplastic fracture behaviour

CFCCs (Continuous Fiber Ceramic Composites) use long fibers as reinforcements. The non-oxide ones, in particular carbon (C) and silicon carbide (SiC) fiber reinforced SiC-based materials (C_f/SiC or SiC_f/SiC), exhibit interesting properties at high temperature, such as creep resistance, high thermal conductivity, low thermal expansion and resistance to thermal shock. For these reasons, their use is proposed for thermally loaded components in space applications such as propulsion systems or thermal protection systems.

Among the techniques for the production of ceramic composites, the Chemical Vapour Infiltration (CVI) is the most promising one. This process is highly flexible as it allows the production of different types of matrix materials and is the most suitable for the realization of complex structures, which minimize the final machining operations. The main advantage over the other infiltration processes consists in the high degree of densification of the preforms, achievable thanks to matrix gaseous precursors able to infiltrate even the smallest porosities of the fibrous preforms and the absence of organic residues, whose elimination by thermal treatment leave a residual porosity. Conversely, long process times are required in order to prevent early surface occlusion of porosities and the consequent partial densification (fig. 2).

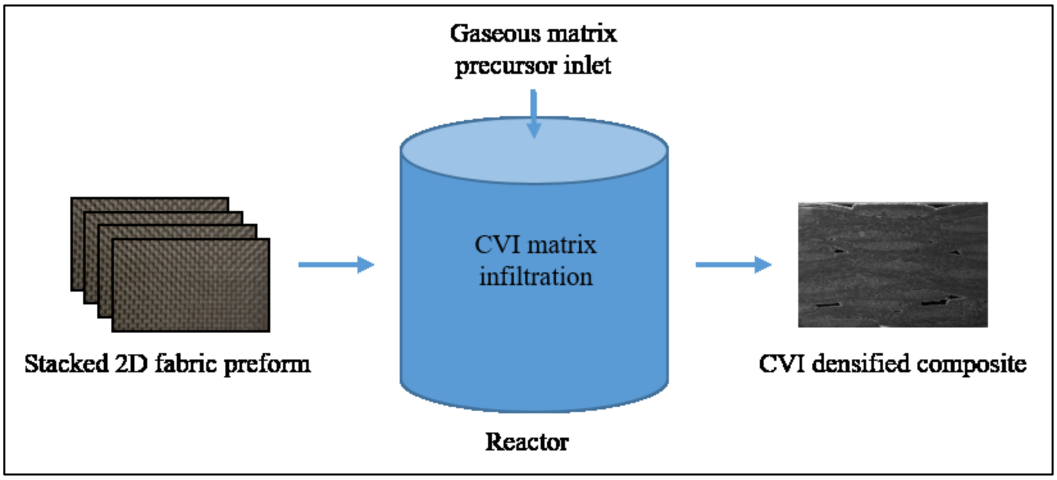

Fig. 2: step outline of composite production by CVI process

In the Laboratory of Materials Technologies Faenza (TEMAF) of ENEA a pilot-sized CVI/CVD plant was set-up since to 2006 (fig. 3).

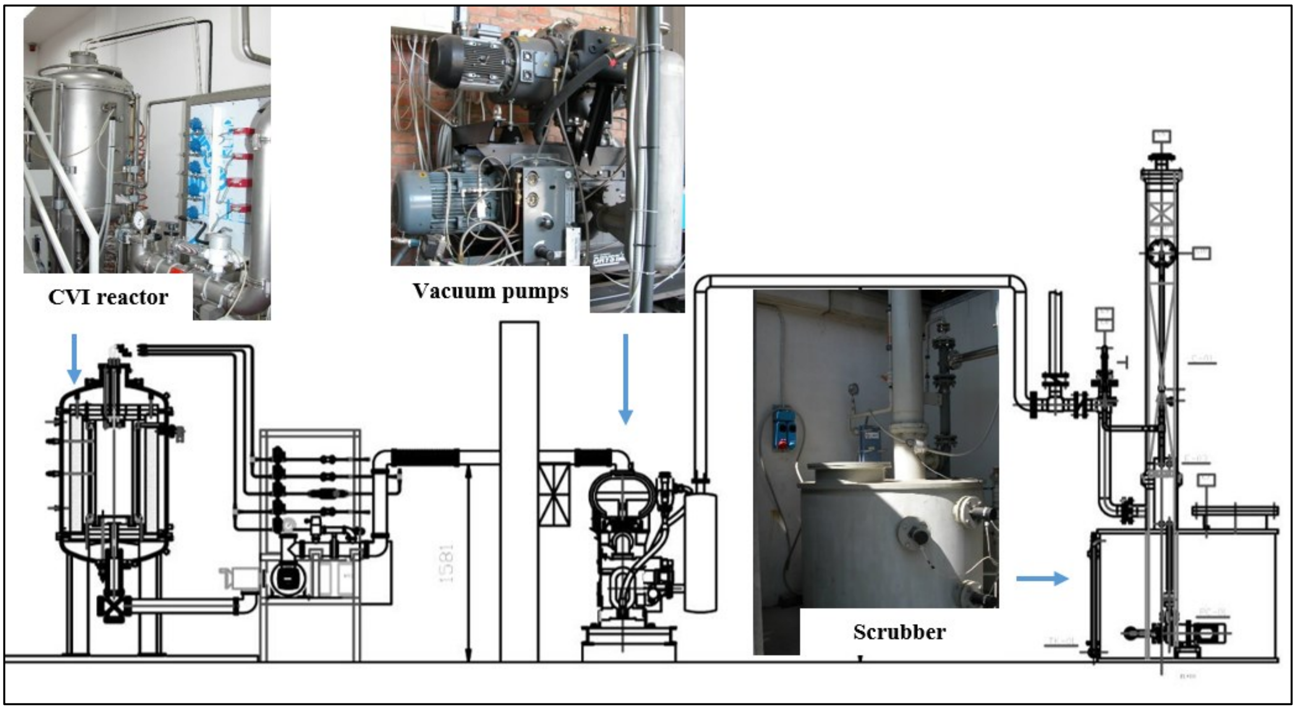

Fig. 3: ENEA CVI plant

The related research activities are mainly focused on the study of CVI process mechanisms and of the produced composite properties.

For instance, the effect of CVI process parameters, such as temperature and residence time, on Pyrolytic Carbon (Py-C) microstructure and infiltration behaviour were investigated (fig. 4). Furthermore, the obtained experimental data, such as the deposition rates of Py-C and the density and porosity values of the produced C_f/C composites, were used for the validation of the calculation codes of the chemical vapour infiltration and deposition (CVI/CVD) processes.

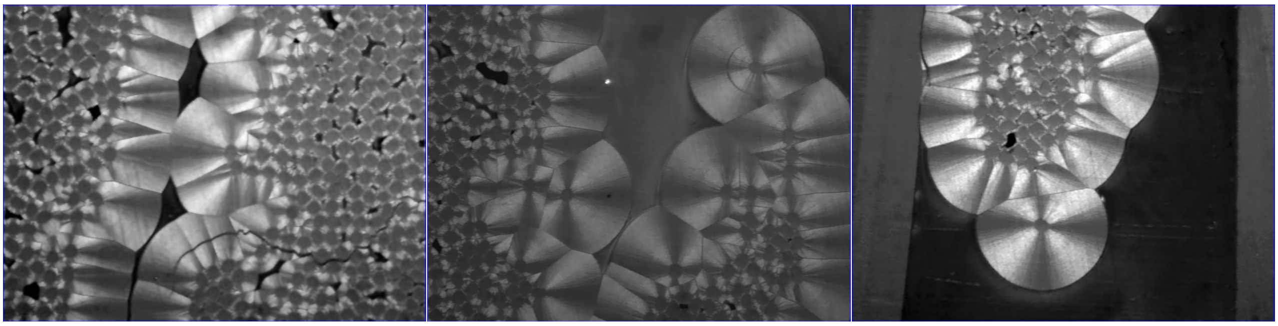

Fig. 4: polarized-light microscopy images of obtained Py-C microstructures

A preliminary study of silicon carbide Chemical Vapour Infiltration and Deposition (CVI/CVD) processes was also conducted: the study aimed at defining the CVI/CVD process parameters, starting from MethylTricoloroSilane (MTS) as SiC gaseous precursor (fig. 5).

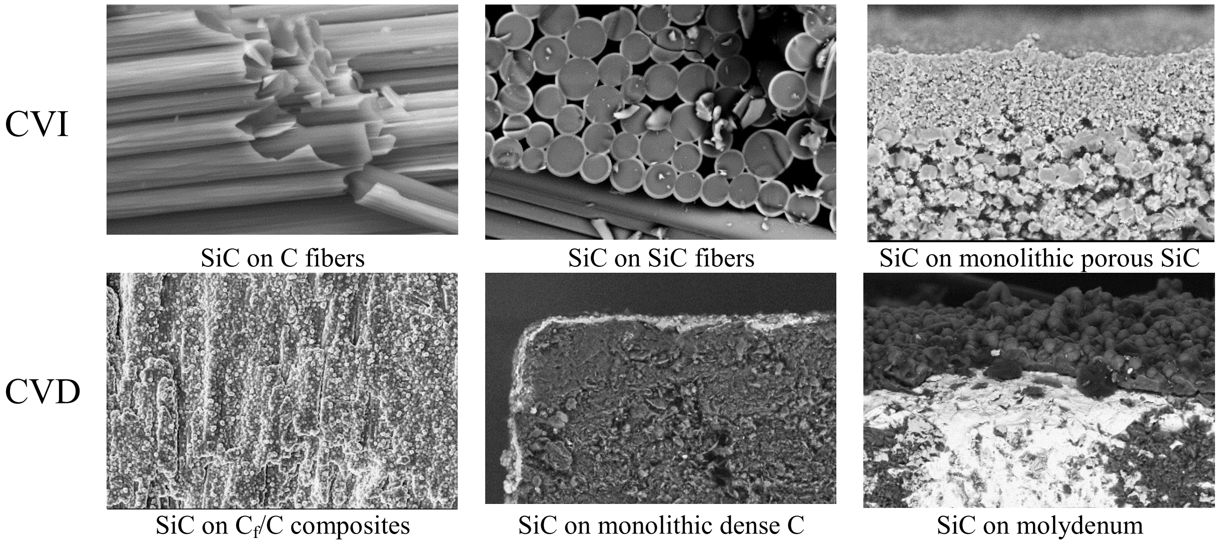

Fig. 5: SEM images of SiC CVI/CVD tests

The researches were carried out under projects, in collaboration with enterprises, universities and research centres and were primarily devoted to the development of components for aeronautical and aerospace applications, such as for example leading and trailing edges of aircraft engine turbine blades. Ongoing project is CEM-WAVE (Novel Ceramic Matrix Composites produced with Microwave assisted Chemical Vapour Infiltration process for energy-intensive industries), funded from the European Union's Horizon 2020 research and innovation programme (https://www.cem-wave.eu/). To spearhead the shift to clean and renewable energies, heavy industry needs best-performing and energy efficient materials that can sustain harsh conditions, such as very high temperatures and corrosive environments. The CEM-WAVE project proposes the use of Ceramic Matrix Composites in harsh-conditions manufacturing settings.

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