Experimental Tape Casting of Adjacently Graded Materials for Magnetic Refrigeration

Functional graded materials are extensively applied in many innovative technologies, e.g. solid oxide fuel cells, solar cells, membranes, piezoactuators, capacitors, and thermoelectric systems. The synergy of advantageous combinations of composites with different composition and/or microstructure together with recently developed option for low cost manufacturing techniques progressively widens the diversity of functional materials design and the variety of their application range. Currently, application requirements in ceramic technology have advanced multilayered systems to a point where layered graded materials with well-controlled dimensional and mechanical characteristics can be successfully produced. This thesis presents a study of adjacently graded ceramic materials, achieved by a novel side-by-side tape casting technique. Side-by-side tape casting produces continuous in-plane adjacently graded thin films. The motivation to create such adjacently segmented structures stemmed from a search of material and a materials design alternative to the expensive rare earth element gadolinium which is widely used as a magnetic regenerator in the emerging magnetic refrigeration technology. Conventional tape casting involves the preparation of specially formulated slurry, which is cast by a blade to a thin flat tape, then dried into flexible so-called green solid tape and can be subsequently sintered into a hard ceramic material. The principal difference and, at the same time, a challenge of the side-by-side tape casting technique includes simultaneous adjacent co-flow of slurries, creating a uniform graded material with a well-defined interface, which is characterised by a high adhesion and no inter-diffusion between adjacent materials. The PhD project focuses on the crucial challenges of the side-by-side tape casting technique: recognising critical parameters which affect the quality of a graded tape, shape and position of the interface area. Studied parameters can be divided into two categories: operational parameters and slurry formulation optimisation. The operational parameters encompass modification of the entire tape caster into a multi chamber unit, establishment of the optimal operating parameters such as casting gap, speed, and slurry level in the tape caster reservoir, and elucidation of the impact of chamber partition design on the quality of the final tape. The second research area focuses on optimisation of the slurry formulation suitable for adjacent co-flow, which includes a detailed study of the rheological behaviour of slurries, influence of slurry density, numerical analysis of the slurry flow beneath the doctor blade resulting in a greater control of material design desired to meet all requirements from the application side. Mechanical tests verified a high adhesion between co-cast materials, indicating that the formed adjacently graded tapes behave as a single material. As the result of the tight collaboration between the present experimentally oriented project and a parallel project on numerical characterisation of tape casting, a new program for controlling the casting thickness was developed and practically applied. This new approach based on a continuous casting speed change, was compared with other approaches to control tape thickness and showed very promising results of decreasing the tape thickness gradient to 3%. In addition to the development of side-by-side tape casting technique, a series of experiments were directed at investigating which of the available tape casting modes (e.g., single-blade, double-blade, casting with use of pump system or the newly proposed speed change mode) forms a uniform green tape with precisely controlled tape thickness. The objective of performing these tests was to decide which tape caster design had to be used for the side-by-side tape casting.

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