Alumina micro-heat exchanger manufactured by Ceramic Injection Moulding

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Résumé :

Le travail concerne le développement d'un nouveau procédé de fabrication d'un échangeur thermique en céramique. Le procédé s'appuie sur le procédé de Ceramic Injection Molding (CIM), qui permet la réalisation des éléments constitutifs de l'échangeur. Ensuite les différents éléments sont assemblés par co-frittage. L'échangeur est caractérisé par un réseau interne de canaux enterrés.

Le papier décrit le mode de développement d'un feedstock d'alumine basé sur des poudres ultrafines et décrit les conditions, d'injection, de déliantage et de co- frittage des éléments. L'interface entre les éléments a été caractérisée par microscopie optique.

Le procédé pourrait être utilisé pour fabriquer des micro-échangeurs thermiques à bas coût de forme complexe dans des domaines variés comme l'énergie ou le refroidissement de l'électronique.

Abstract :

This work concerns the development of an innovative processing route to manufacture a new design of ceramics micro-heat exchanger.

The manufacture is based principally on the Ceramic Injection Moulding process of the different elements of the micro-heat exchanger. Furthermore, the different elements are cofired in order to provide directly the part. The micro heat exchanger is characterised by a complex network of inner channels.

The paper focuses on the alumina feedstock based on ultrafine alumina powders and on the conditions of injection, debinding and co-firing, developed essentially for this study. Moreover, the interfaces between the co-fired elements have been characterized by optical microscopy.

This process may be applied to design complex and precise microstructures for mass produced micro heat exchangers, cold plates and micro reactors than can be used for various large scale applications in the field of energy and electronic cooling.

Mots-clefs :

microPIM ; heat exchanger ; alumina

1 Introduction

Micro powder injection moulding (or micro-PIM) is a technique which has been largely developed in recent studies [1-9]. This technique can be used for manufacturing micro parts for large-scale production. This process allows also the replication of very fine details, typically in the order of magnitude of the size of the powder. However, the development of feedstock for micro-PIM with nanopowders is difficult as the viscosity of the feedstock then increases drastically [2]. The majority of feedstocks for microPIM are therefore composed of micrometer size powder. They allow replicating details of a few 10th micrometers [1].

Among several applications, micro heat exchangers and micro reactors appear to be an important issue for the micro-PIM. Several demonstrators have been manufactured by several authors [10, 11], until now.

In this research work, we have developed a process chain to produce a micro heat exchanger. The different processing steps concern:

- the development of feedstock with ultrafine powders of alumina

Due to the thinness of the inner channel patterns, it is required to use ultrafine powder to allow the replication of such a fine details. A new kind of feedstock was developed, based on the blending of bimodal spherical populations of powders,

- the injection, debinding and co-sintering of the plates

The quality of the interface between the former plates has been characterized by optical microscopy.

In this paper, we describe the different processing stages for the fabrication of a multi-layer micro heat exchanger. This heat exchanger presents several originalities:

- it is made on pure alumina,
- it embeds a complex inner channel network.
- it is assembled directly by co-firing: the different plates are assembled with the help of tapes inserted between plates.

2 Experimental

Ceramics powder

In this study, we have used two different kinds of ceramic powders, called powder A and B provided by the French company Baikowski. Table 1 and 2 show some characteristics of these powders.
The powders chosen are specific for the injection process and their particle sizes were chosen in order to obtain high solid content for the feedstock.

Powder A : alumina	
D50 (µm)	0,33

Powder B : alumina	
D50 (µm)	0,18

Table 1: Size of the powders used in this study.

Binder system

A blend of polypropylene, (86.6 wt%), and paraffin wax (8.6% wt%) was used. A small amount (4.8 wt %) of stearic acid was added to the polymer blend in order to improve the powder dispersion

Injection of the plates

A Battenfeld 250 plus press has been used to inject the parts.

Debinding cycle

In this study, we have made only thermal debinding cycle. This cycle was performed at 550°C for 3 hours. After completion of the debinding cycle, it was checked that there were no residual organic material.

Bonding tapes

In order to permit the assembly of plates during co-firing, we have used some home-made tapes constituted of nanosized alumina powder (10nm) with a matrix of polystyrene. These tapes have been inserted between the plates, just before co-firing. The thickness of the tapes is around 100 microns. During the sintering cycle, the tapes are debinded and the nanopowder on the tapes are sintered simultaneously with the plates.

Sintering cycle

The sintering cycle consisted in a cycle at 1700°C during 3 hours under air.

3 Results

In this study we have set up the complete process chain from the powder to the heat exchanger. The complete chain is described in figure 1.

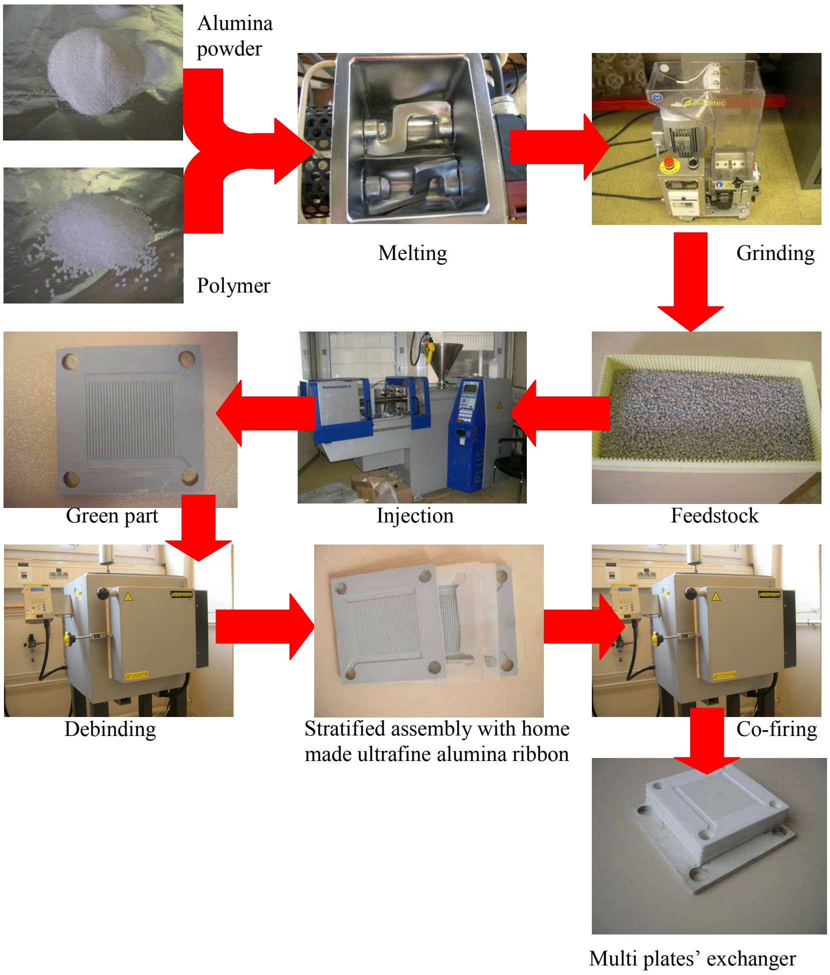

Figure 1: Sketch of fabrication of the heat exchanger.

Feedstock preparation

In this study, we have mixed several types of alumina with different particle sizes (see table 1) in order to increase the solids content within the feedstock. With this methodology, it was possible to reach 67% of solid content even the average particle size of the powder was quite small. Table 2 displays the composition of the feedstock developed for this study.

Materials	**Volumic weight (g/cm^3)**	**Massic %**	**Volumic %**
Powder A	3,96	11	8
Powder B	3,96	78	58
PP	0,9	9	30
PW	1,03	0,9	2,6
AS	0,94	0,5	1,6

Table 2: Compositions of the feedstock optimized.

Injection of the part

A typical micro heat exchanger has been designed in order to produce it by overlapping of identical plates as illustrated in figure 2.

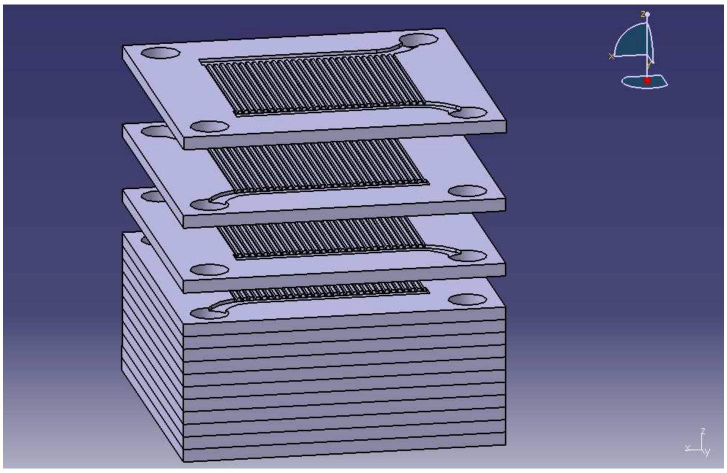

Figure 2: Structure of the heat exchanger.

Each plate has 30 microchannels (500 µm width and 500 µm depth). Inlet and outlet headers were not optimized for even distribution through the channels.

On the figure 2, we can notice that between 2 successive plates, we impose a rotation of 180°.

Debinding tests were made on four samples. Results are shown in table 3. Parts are fully dense, without cracks and have undergone isotropic shrinkage. The binder removal is 100%.

	Weight (g)		results	
sample	green parts	brown parts	wt lost (%)	Binder removal (%)
1	7,28	6,51	10,6	100
2	5,14	4,59	10,7	100
3	6,32	5,64	10,7	100
4	4,82	4,30	10,7	100

Table 3: Binder removal at debinding stage

Co-firing results

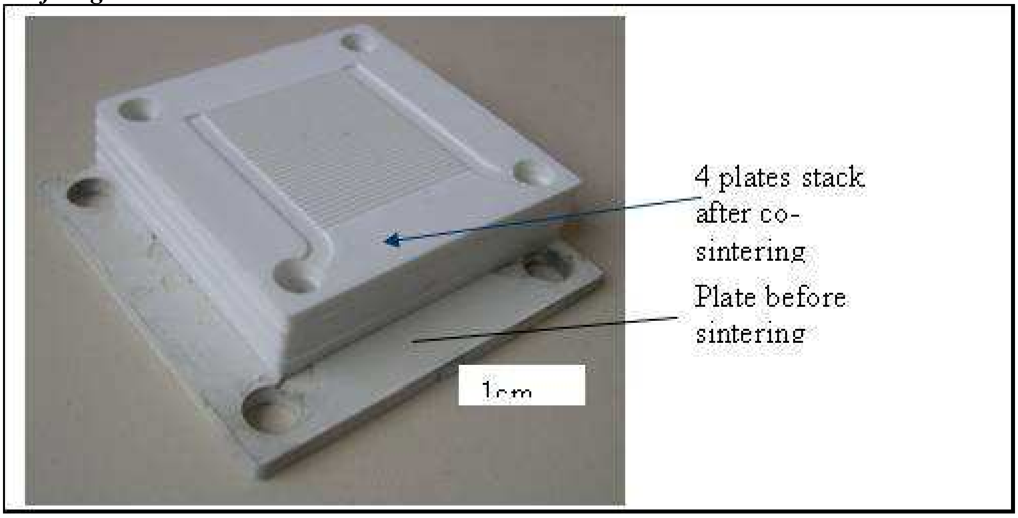

Figure 3: final part

One ribbon has been inserted between each plate (see figure 1) before co-firing in order to assist the joining of the plates. The stack has been sintered with an applied load (1 kg) on the top surface. After sintering, no cracks or geometry distortion did appear. The ribbon has been correctly debinded. Density measurements made by Archimedes method gave an average value of 95% of relative density for the final part. A 4 plate parts is displayed in figure 3.

Characterization of the interface between the plates after co-firing

A second heat exchanger has been made and sawed in order to observe the interface by optical microscopy. Figure 4 allows us to assess he interface observed by means of optical microscope. The contact between two plates is quite good.

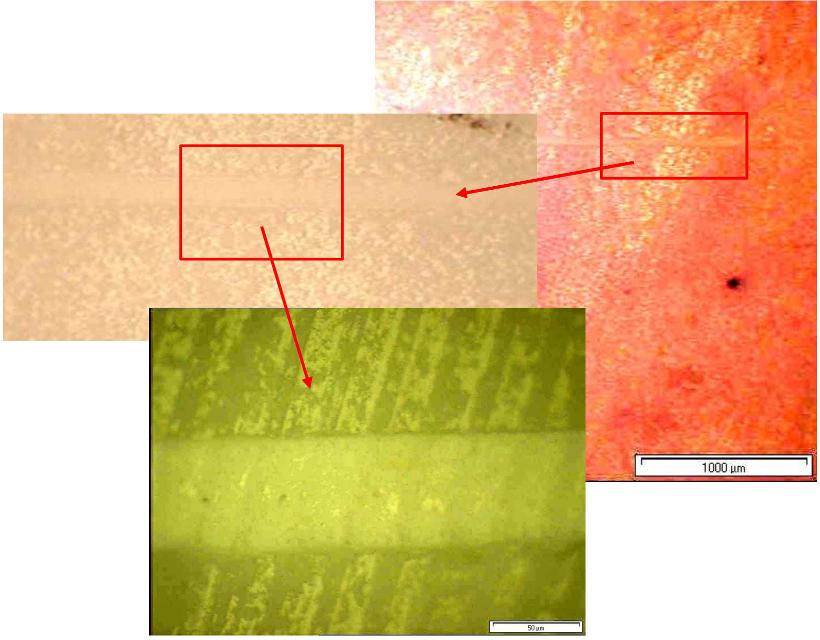

Figure 4: Optical microscopy of the interface between 2 plates at different magnifications.

After sintering the remaining thickness of the former tape can be seen at the higher magnification (bottom image of figure 4). It is estimated at 75 microns. We observe that the interface region is clearly crack-free.

4 Conclusions

A new process chain has been developed in order to manufacture complex-shape 3D parts like heat exchangers or micro reactors. This process is based on the micro Powder Injection Molding process. We have developed a feedstock based on a blend of ultrafine alumina powders. The optimization of the binder system and the proportion of the two different types of powders has led to the possibility to make a feedstock with a high solids content (66 vol %) and good injectability.

To get a good interface between the plates, a specially designed tape, made essentially of a mixture of nanometric alumina powders and polymers was developed. This tape is inserted between the plates just before sintering in order to insure a good assembly between the plates.
Optical observations have confirmed the good cohesion between the plates. No cracks have been observed.

References

[1] Ruprecht R, Benzler T, Hanemann T, Müller K, Konys J, Piotter V, et al. Various replication techniques for manufacturing three-dimensional metal microstructures. Microsyst Technol., 1997; 4:28–31.

[2] Piotter V, Benzler T, Gietzelt T, Ruprecht R, Hausselt J. Micro powder injection moulding. Adv Eng Mater., 2000; 2(10): 639–42.

[3] Piotter V, Bauer W, Benzler T, Emde A. Injection moulding of components for microsystems. Microsyst Technol., 2001; 7: 99– 102.

[4] Liu ZY, Loh NH, Tor SB, Khor KA, Murakoshi Y, Maeda R. Binder system for micro powder injection moulding. Mater Lett, 2001; 48:31 – 8.

[5] Murakoshi Y, Shimizu T, Maeda R, Sano T. High aspect ratio structuring by IPC etching and metal and ceramics forming. MicroMaterials Conf, Berlin, April 17–19; 2000.

[6] Merz L, Rath S, Piotter V, Ruprecht R, Kleissl JR, Hausselt J. Feedstock development for micro powder injection molding. Microsyst Technol., 2002; 8:129–32.

[7] Ruprecht R, Gietzelt T, Mqller K, Piotter V, Haugelt J. Injection molding of microstructured components from plastics, metals and ceramics. Microsyst Technol., 2002; 8:351– 8.

[8] Liu ZY, Loh NH, Tor SB, Khor KA, Murakoshi Y, Maeda R, et al. Micro-powder injection molding. J Mater Process Technol., 2002;127(2): 165–8.

[9] Rota A, Duong TV, Hartwig T. Micro powder metallurgy for the replicative production of metallic microstructures. Microsyst Technol., 2002; 8: 323 –5.

[10] Rota A, Duong TV, Hartwig T. Wear resistant tools for reproduction technologies produced by micro powder metallurgy. Microsyst Technol., 2002; 7:225 – 8.

[11] R. Knitter A1, D. Göhring A1, P. Risthaus A1, J. Haußelt, Microfabrication of ceramic microreactors, Microsystem Technologies, Volume 7, Number 3, p. 85 - 90

[12] R. Ruprecht A1, T. Gietzelt A1, K. Müller A1, V. Piotter A1, J. Haußelt. Injection moulding of microstructured components from plastics, metals and ceramics, Microsystem Technologies, Volume 8, Numbers 4-5. P 351 - 358