Investment Cast Near-Net-Shape Components Based on Cellular Metal Materials

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Abstract

Cellular metal materials provide an enormous potential for application. Precision cast open cell structures with open porosity attract special interest. The permeable periodical three-dimensional cellular structures with their particular physical, chemical and mechanical properties define an innovative, multi-purpose functional material. The high ratio of surface to volume opens a wide range of possible applications.
Since 1996 cellular metal materials have been cast at the Foundry-Institute at the Technical University of Aachen by applying precision casting technique which enables the manufacture of complex near-net-shape components. These can be used for components in heat exchangers, filters, as catalyst surfaces, as weight saving constructive elements, deformable energy absorbers etc. Composites consisting of shaped cellular structures and massive parts were produced in a one step casting process. Typical properties are porosities up to 98% and pore sizes of 10 to 30 pores per inch.

1 Introduction

Cellular metal materials (CMMs) define an innovative multifunctional material. With increasing availability of the structures the range of possible applications widened and the required properties are optimised. Closed and open cell structures can be manufactured by a variety of processing routes [1-5]. Most of the closed cell structures show irregular pore sizes and pore size distributions and are mainly restricted to a few aluminium alloys.

Precision cast open cell structures attract special interest due to their particular physical, chemical and mechanical properties. Basic structure parameters are pore size, volume fraction and matrix alloy. The regular three-dimensional structures enable pore volumes up to 98% and have an extremely high surface to volume ratios. Another outstanding characteristic is their permeability.

2 Experimental

At the Foundry Institute at the Technical University of Aachen the precision casting of open cell structures has been picked up, **Fig.1**. Reticulated polyurethane foams are used as a starting material for the open cell structure. The foams are available in a variety of cell parameters and can be modified by different techniques yielding among other properties an increase in volume fraction and a modification of the cell structure. The foams are cut into the desired sizes and geometries. Massive parts as well as running and gating systems are manufactured by typical investment casting techniques like wax injection moulding. Then the wax patterns and shaped foams are assembled and prepared for the mould production. The

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ceramic shell moulds are produced by conventional techniques. Used shell mould materials are dependent on the cast alloy. Experiments have been worked out for alloys based on Al, Cu and Zn. After casting the ceramic has to be removed very carefully in order not to damage the filigran metal structure.

The structure properties like pore size, volume fraction and matrix alloy offer a wide range of possible combinations according to user demands, **Fig. 2**. The single structure properties can be varied independently from others and consequently application requirements can be met perfectly.

Semi-products and near-net-shape components were produced in different alloys. Composites were cast in a one-step casting process and optimised according to customer requirements.

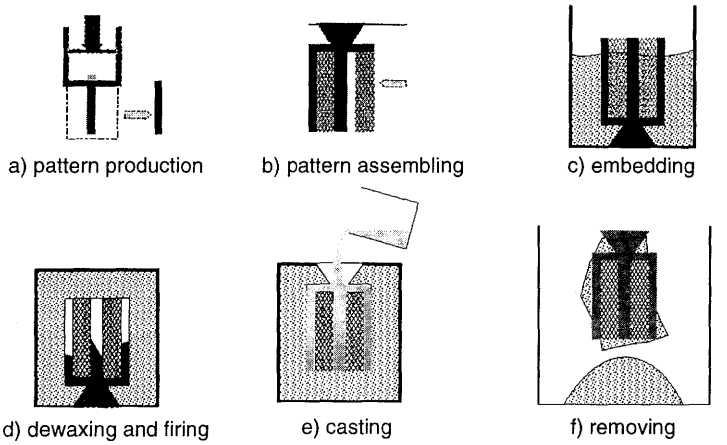


Fig. 1: Schematic of the precision casting process for the production of near-net-shape CMMs.

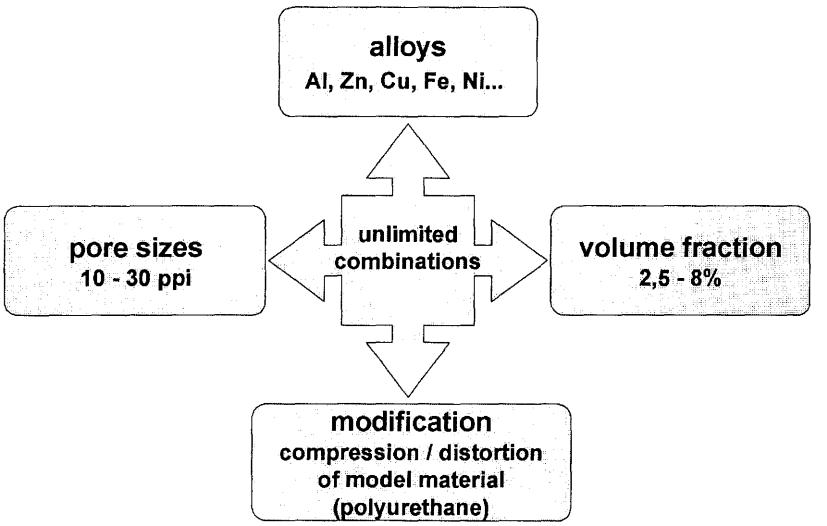


Fig. 2: The variety of parameters offers a wide range of combinations.

3 Results

For Al- and Cu-based alloys the castability has been evaluated. High quality cell structures from 10 to 30 pores per inch (ppi) were solidified, **Fig. 3**. Thin-walled structure diameters of less than 0.5 mm were completely infiltrated and the moulding material was modified in order to achieve an easy removability from the open cell structures. Mechanical strength and chemical resistance of the ceramic were taken into consideration. The knowledge of casting Al-, Cu- and Zn-based alloys has also been evaluated for high temperature alloys. With rising casting temperature the required strength and the chemical resistance of the moulding material increases, whereas higher strength of the moulding material decreases the removability of the ceramics without destruction of the CMMs.

The next step was the casting of different types of composites in different sizes regarding applications like heat exchanger elements, **Fig. 4**. Simple sandwich structures can be cast as well as tubes with open cell structures inside. The boundary between massive part and CMM was found to be perfect. Basic composites like sandwiches and simple plates with shaped CMMs were used to investigate their heat transfer properties for usage in a heat pump cooling machine [6]. The heat exchanging modules were then optimised for the application in close cooperation with the end user. The final geometry with the best thermodynamic properties is shown in **Fig. 5**. Sandwich structures consisting of massive plate and CMM on both sides were cast around stainless steel tubes. The modules are presently tested in a 2 kilowatts' cooling machine, where the CMMs are filled with an absorption salt. The heat transfers between CMM and massive part and between massive part and steel tube are decisive for the efficiency of the cooling machine. The composites were realised in a one step casting process and present the best thermodynamic properties when compared to modules which were fixed together from the single parts Al-CMM, massive aluminium plate and integrated steel tube.

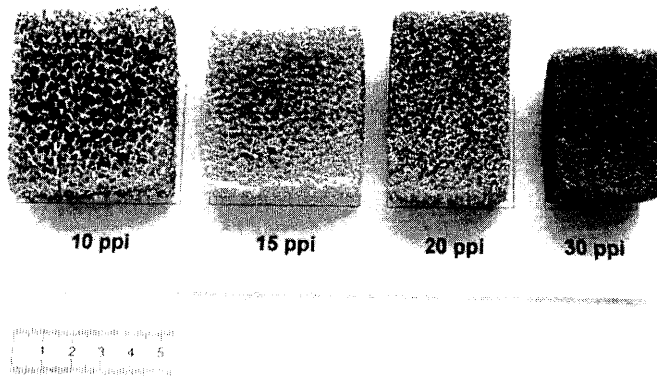
Complex shaped components were also produced in larger dimensions, **Fig. 6**. Precision cast CMMs are in general suitable for applications like energy absorbers where especially their mechanical properties are required. The corrosion resistance then can be optimised by choosing the most suitable basic alloy as required for the application.

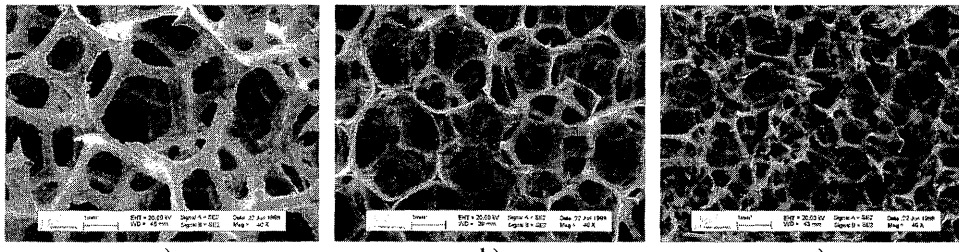
4 Discussion

High quality near net shape CMMs as semi-products and composites consisting of CMM and solid parts were cast. Heat exchanger modules were successfully applied in heat pump cooling machines. Major aims of the ongoing research work are

- the optimisation of each of the precision casting process steps for a more economic production and
- the adaptation for new applications.

The cooperation with users is very important for developing shaped cellular structures according to properties. Although the structures can be produced, extensive research work is necessary for the fundamental characterisation of mechanical, physical and chemical properties. The wide range of possible combinations concerning matrix alloys based on Al, Zn, Cu, Fe, Ni, volume fraction and pore size requires systematic scientific investigations to take full advantage of the cellular materials with regard to the application.
The regular structures can be produced as semi-products or as near-net-shape parts within the possibilities of the precision casting process. There are no remarkable limits concerning the matrix metal alloys.





a) b) c)

Fig. 3: Open cell structures between 10 (a), 20 (b) and 30 ppi (c) were realised in excellent quality for aluminium and copper alloys.

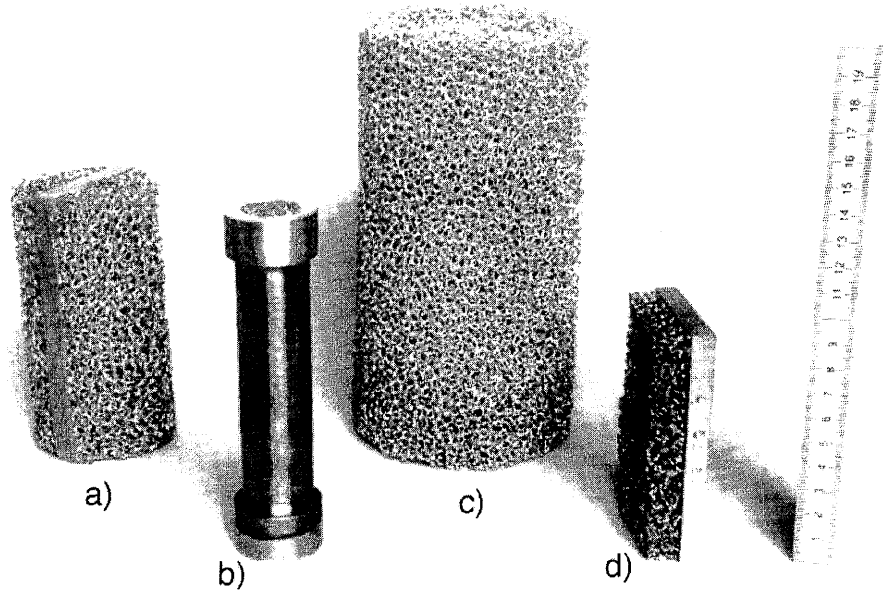


Fig. 4: Examples for different kinds of precision cast CMM parts. Heat exchanger module with shaped CMM (a), near-net-shape tube with CMM inside (b), shaped semi-product (c) and CMM-solid plate sandwich (d) for the investigation of physical properties.

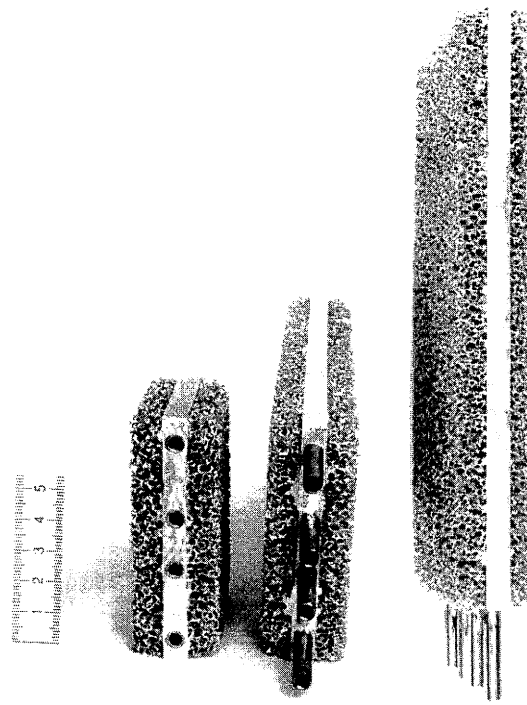


Fig. 5: Module of a heat exchanger, cast in a one step. The perfect composites of CMMs, massive aluminium plates and stainless steel tubes assures an effictive heat-transfer.

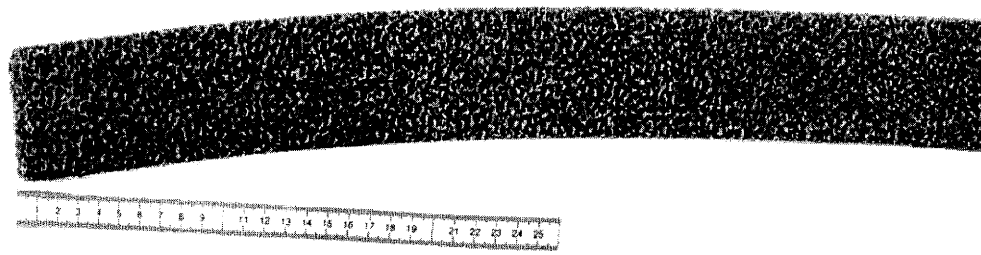


Fig. 6: Even larger components can be verified. Zinc-alloy crash-absorber element of 57 cm in length.

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