Powder Metallurgy & Mining

Editorial Open Access

Porous Metallic Materials Produced by P/M Methods

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Introduction

Materials produced by P/M almost invariably contain some pores or voids. Normally, our aim is to minimise the porosity to achieve a dense material for better mechanical properties. In some cases, however, pores are desirable as they give the material functions that dense solids do not possess. In these cases, the objective becomes to produce porous materials with controlled pore shape, pore size and porosity to bring about the desired functional properties.

In essence, porous materials are a special class of composite materials, composed of one or more solid phases and a gaseous phase. The functionality of the porous material derives from the combinations of distinctive characteristics of the solid and gaseous phases. The solid phases provide geometrical architecture, strength, electrical conductivity, thermal conductivity, magnetic shielding, and acoustic barrier, just to name a few. The gaseous phase (usually air) offers compressibilityor allows fluids to flow through.

Porous materials produced by P/M are usually metallic based and fall into two categories: porous metals and metal matrix syntactic foams. Porous metals are also called metal foams or cellular metals. These terms are often used interchangeably, although they have different connotations. Metal matrix syntactic foams are a special type of particulate reinforced composites where the hollow or porous ceramic particles are imbedded in a metal matrix.

This short article describes the characteristic features of these materials in terms of manufacture, structure, properties and applications.

Manufacturing Methods

There exist many methods for manufacturing porous metallic materials, which can be categorised in several different ways [1-3]. One classification is according to the state of the metal used to build up the matrix or cell walls.

In physical and chemical vapour deposition, the base metal is deposited onto a supporting template through condensation of metal vapours or chemical reactions from gaseous precursors. Similarly, electroplating can also be used to deposit metals onto sacrificial foam structures. These deposition methods have low productivity and often require special equipment. They are more suitable for producing porous structures with high surface areas and thin cell walls, especially from expensive metals.

Most metal foams are produced by a liquid route. Foaming is the simplest and most popular choice, where gases are injected into the melt or generated within the melt to create bubbles. The foamed melt solidifies, resulting in a high porosity and close-celled solid foam. The foaming processes are cheap, but the as-produced metal foams often have poor qualities, characterised by non-uniform distributions of pore sizes and porosities. Another approach is investment casting, which creates a metal replicate of polymer foam. It is a rather expensive process but produces metal foams with high quality.

The solid route methods for producing porous metals are based on P/M and are oftencollectively called space-holder methods. In these methods, a metal powder is first mixed with a filler material in the powder form. The mixture is then compacted into a preform, which is subsequently sintered (either before or after the filler material is removed) so that the metal particles are bonded into a solid network. The spaces held by the filler particles in the preform become the pores in the resultant porous metal (thus the name space holder method).

Three manufacturing processes represent the different methods for the removal of the filler materials. Laptev et al. [4] used ammonium bicarbonate particles as the space holders. After compaction, the ammonium bicarbonate particles were removed by decomposition at a temperature below 200°C. The porous compact was then sintered at a much higher temperature. A problem of this process is that the porous structure may collapse when the filler material is removed, especially for large components, because no diffusional bonding between the metal particles can form at such a low decomposition temperature. The Sintering and Dissolution Process (SDP) [5] uses NaCl particles as space holders, which are dissolved in water after sintering is completed. One disadvantage of SDP is that it can only be applied to metals with sintering temperatures lower than the melting point of NaCl. The Lost Carbonate Sintering (LCS) process [6,7] uses potassium carbonate particles as space holders. Because potassium carbonate has a high melting point (901°C), most metals can be sintered below this temperature to form full or partial bonding between the metal particles. As a consequence, LCS can be applied to a much wider range of metals and alloys. More importantly, potassium carbonate can be removed either by dissolution in water or by decomposition at a temperature above its melting temperature, making LCS a versatile and efficient process.

The methods used for manufacture particulate metal matrix composites can be adapted for metal matrix syntactic foams. However, stir casting is rarely used because it is difficult to mix the hollow or porous ceramic particles into the melt due to their extremely low densities. Pressure infiltration casting is normally used for producing syntactic foams of low-melting-point metal matrices, such as aluminium [8,9]. P/M can be used for producing other metal matrix syntactic foams,e.g., titanium matrix syntactic foam [10],where liquid processing is not suitable, Unlike pressure infiltration casting where the volume fraction of the metal matrix is largely fixed, metal matrix syntactic foams produced by P/M can have variable metal to ceramic particle ratios.

It should be noted that P/M methods generally have higher costs

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Received July 10, 2013; **Accepted** July 12, 2013; **Published** July 13, 2013

Citation: Zhao Y (2013) Porous Metallic Materials Produced by P/M Methods. J Powder Metall Min 2: e113. doi:10.4172/2168-9806.1000e113

due to the usage of high cost powders. They should only be used where liquid route methods are not suitable or cannot meet the quality standard.

Porous Structure

Porous metals produced by the space holder methods have well defined porous structures. In effect, the pores are negative replicas of the particles of the filler material, so their shapes and sizes are determined by the morphology of the filler material particles. The porosity is usually slightly greater than the volume fraction of the filler material in the powder mixture preform, because of the voids existent in the powder mixture.

Porous metals produced by the space holder methods have open pores, i.e., the pores are interconnected. The porosity can be varied in 50–85% without the filler material being trapped in the metal matrix [11]. Although the porous structure is macroscopically uniform, the distribution of the pores is random at the pore size level, leading to high tortuosity. It is also possible to produce hybrid or gradient structures with different pore sizes and/or porosities in a single component.

An important feature of P/M porous metals is that they have bimodal pores,macro-pores resulting from the space holder particles and micro-pores on the pore wallsdue topartial sintering of the metal powder matrix [12]. As a result, the macro-pores have rough internal surfaces.

The porosity of the metal matrix syntactic foams is almost entirely derived from the hollow or porous ceramic particles. The pores are all closed and the porosity is limited, typically less than 50%, although it can be increased by using bimodal ceramic particles [13].

Properties and Applications

Like all other metal foams, porous metals produced by P/M methods have good energy absorbing capacities and can therefore be used as impact energy absorbers. However, they are not likely to be competitive due to higher production costs. The only area these materials are favourable is probably in damping applications due to high internal friction.

P/M porous metals are mainly used for their functional properties, including thermal, acoustic and chemical properties.

Porous metals can be used as heat exchangers in forced cooling devices. Their heat transfer coefficients are markedly higher than conventional sintered metals [14,15]. The optimum heat transfer performance is achieved when heat conduction in the metal matrix is balanced by heat convection by fluid flowing through the porous metal. Porosity is the most critical parameter as it affects both thermal conductivity [16] and fluid permeability [15]. The best heat transfer performance is obtained in the porosity range of 60-70%.

Porous metals can be used as sound absorbers, especially in harsh environments where polymeric materials are not suitable or when they are also required to have other functions, e.g. supporting loads. Pore size, porosity and pore morphology have significant effects on the sound absorption coefficient [17,18].

Metal matrix syntactic foams are mainly used for structural applications because of their high specific strength and high specific stiffness. One shortcoming of the syntactic foams produced by P/M is lower ductility than those produced by casting.

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Citation: Zhao Y (2013) Porous Metallic Materials Produced by P/M Methods. J Powder Metall Min 2: e113. doi:10.4172/2168-9806.1000e113