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Review

Replication of microchannel structures in WC–Co feedstock using elastomeric replica moulds by hot embossing process

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ABSTRACT

Hot embossing is a net shaping process that is able to produce the micro-components of polymers with intrinsic and complex shapes at lower cost compared with machining and injection moulding. However, the emboss of hard metals, such as WC–Co, is more challenging due to their high thermal conductivity and ease of agglomeration. Thus, a WC–Co alloy mixed with a wax-based binder feedstock was selected. The formed feedstock exhibited pseudo-plastic flow and was successfully embossed (green part). Here, we developed a novel process that is used to replicate polymer microfluidic chips while simultaneously reducing the channel surface roughness of the mould insert, yielding optical-grade (less than 100 nm surface roughness) channels and reservoirs.

This paper concerns the replication of metallic microfluidic mould inserts in WC–Co and the parameters associated with feedstock formation via a hot embossing process. A suitable formulation for micro-powder hot embossing has been established and characterised by thermogravimetric analyses and measurements of mixing torques to verify and quantify the homogeneity of the proposed feedstocks. The relative density of the samples increased with processing temperature, and almost fully dense materials were obtained. In this work, the effects of the sintering temperature on the physical properties were systematically analysed. The evolution of the metal surface morphology during the hot embossing process was also investigated. The results indicate that the feedstock can be used to manufacture micro-fluidic die mould cavities with a low roughness, proper dimensions and good shape retention. The shrinkage of the sintered part was approximately 19–24% compared with that of the brown part.

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1. Introduction

Recently, micro-structured parts have been manufactured using several methods, including mechanical machining, lithographic processes, epitaxy and ion beam technologies. Most of these methods are relatively expensive, have time constraints and geometry limitations with poor dimensional accuracy, and are sometimes hindered by excessive waste material. For example, micro-milling is a relatively simple technique that is widely used to manufacture hard moulds and can produce channel features down to 50 μm; however, the surface roughness is generally quite poor and insufficient for most microfluidic applications [1–5].

Today, other micro-manufacturing technologies [6–8], such as micro-injection moulding [9–12], casting [13,14] and micro-hot embossing [15,16], have been developed for different applications such as biochemical-MEMS. The hot embossing process (HE) is one of the most important and promising technologies that has been recently developed. This process is commonly used for the manufacturing of micro-electro-mechanical systems (MEMS), micro-lenses and micro-optical elements, especially in polymeric materials [17–19]. The technique often uses hard tools with a high surface roughness (often on the micron scale) and micro-channels that generate a decrease in the overall efficiency of fluidic flow and often compromise the optical quality [20–22]. These micro-fluidic devices are extensively used for various types of bio-chemical analyses such as waste water monitoring, identification of environmental toxins, targeted drug delivery, analysis of DNA sequences and point-of-care diagnostics [23–26]. Therefore, powder hot embossing is a promising net shaping process that is able to meet the all of these requirements [27–30]. This technique opens the path to many industrial applications due to the high homogeneity of the embossing on large surfaces [31]. The technology and knowledge behind powder hot embossing involve a combination of powder metallurgy and the micro-hot embossing process.

In general, powder hot embossing consists of four stages: mixing of the powder and binder to prepare the feedstock, hot embossing using elastomeric stamps to replicate the hard mould inserts, debinding to remove the binder constituents and sintering to promote the diffusion of the powder to achieve the required properties [32,33]. However, the life of the mould inserts could also be a very important aspect to consider. During the repetitive cycle of micro-replications (injection, hot embossing…), the mould inserts must be able to resist the high clamping force of the machine and fatigue, abrasion, etc. Thus, we must select tungsten carbide cobalt (WC–Co) for elaboration of our micro-fluidic mould inserts. Tungsten carbide cobalt is an alloy with a hard ceramic phase, tungsten carbide (WC), and is expensive and extremely difficult to machine due to its high hardness and ductile metallic phase, cobalt (Co) [34,35]. Thus, most WC–Co is produced through powder metallurgy processes, such as powder compaction. The important properties of WC–Co are its hardness, strength, high breaking and beating ductility and high electrical and thermal conductivity [36,37]. By varying the metallic cobalt content and the tungsten carbide grain size, important properties of the alloy can be specifically adapted. Thus, the two objectives of this study are to investigate the micro-replication by hot embossing and the effect of the sintering temperature on the mechanical and physical properties of the sintered mould insert.

In this paper, innovative solutions are proposed and developed for manufacturing metallic tools to easily reproduce micro-structured surfaces, with a lateral resolution less than 100 nm for feedstocks with very low viscosity. The recent interest in powder hot embossing stems from the need to prepare a low-cost mould cavity characterised by a lower surface roughness, a higher shape accuracy, great hardness and

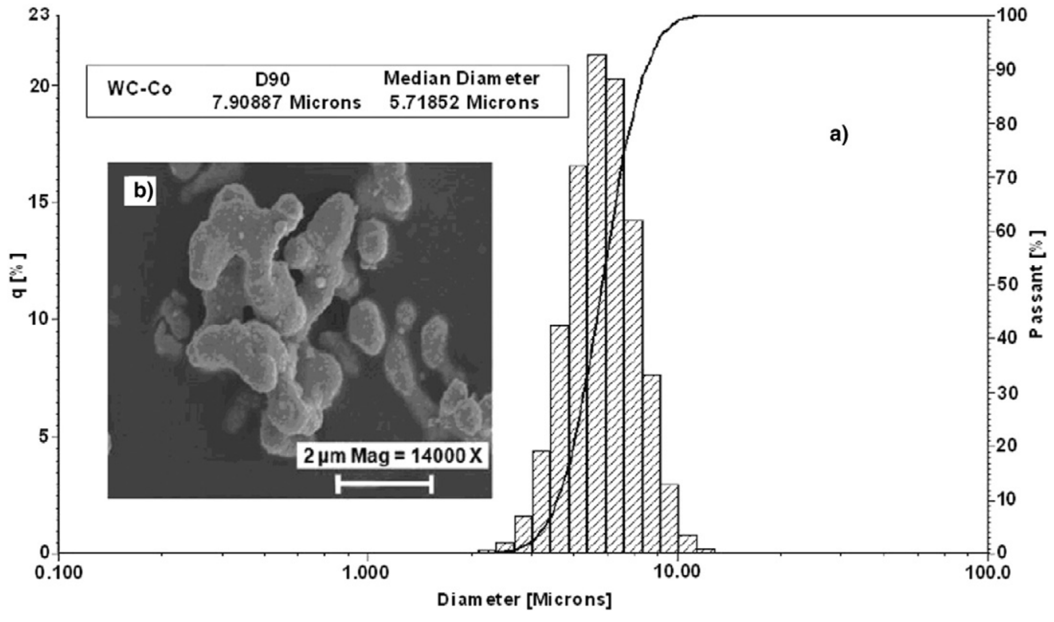

Fig. 1. (a) The particle size distribution for the WC–8 wt.% Co powders and (b) SEM image of WC–8 wt.% Co composite powder.