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The effect of Micro-arc Oxidation treatment on the microstructure and properties of open cell Ti6Al4V alloy foams

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ABSTRACT

Micro-arc Oxidation is a widely used technique to produce thick, hard and strong adherent coatings on the transition metal surfaces. In the present study, Micro-arc Oxidation process was successfully applied to the open cell Ti6Al4V alloy foams which were manufactured by the use of the replication technique and powder metallurgy method. The morphology, microstructure and phase composition of the foam materials were investigated by XRD and SEM examinations. The coating is primarily composed of Al_2TiO_5, α-Al_2O_3 and γ-Al_2O_3 phases. Additionally, mechanical properties of foam materials were characterized by compression tests which were performed on the samples. It is found out that the mechanical properties of the foam materials were significantly improved when compared to the untreated foam materials.

1. Introduction

Nowadays, ceramic, metal or polymer based porous materials increasingly attract the interest of scientists due to fact that they have a number of potentials [1–5]. These materials can display a variety of physical, chemical and biological properties owing to their porous structure. The porous ceramics could be used as thermal insulating materials, fire protection materials, filters or catalysts due to their unique structures and properties such as low density, low thermal conductivity, high permeability, high temperature resistance and high resistance to chemical attack. On the other hand, metal based porous materials can also exhibit low density, good energy absorption capacity, high shock and vibration damping properties, and biocompatibility. With the help of these distinct properties, in particular, metal based foams are foreseen that in the 21st century, they have potential usage in areas ranging from space technology to automotive technology and from construction to medical technologies [3–7].

It is known that the structure of open cell foam materials consists of struts and pores which are connected together. And also, their surface is always subject to outdoors environment conditions. Yet, these distinctive properties of open cell foams could be increased by using a surface treatment technique applied to surface of open pores and struts [8,9]. It is possible to have a significant effect on the properties of struts and pores by coating the surface of struts and pores, so as on foam structures. It is clear that the mechanical properties of foam materials are determined according to the deformation behaviour of these struts. So, the beginning of deformation in the foam structures only takes place by bending these foam struts. As the coating thickness increases, the strength of foam materials does so.

The Micro-arc Oxidation (MAO) process, also called as Plasma Electrolytic Oxidation (PEO) [10], is a relatively novel surface modification technique to produce thick, hard and well-adhered ceramic based coatings on the valve metals such as Ti, Al, Mg, and Zr, and their alloys in a suitable electrolyte [11–15]. The process can improve their corrosion resistance, wear behaviour and various other functional properties like anti-friction, thermal protection, optical, dielectric etc., properties [12–18]. The MAO treatment is based on anodic oxidation of these metals in aqueous electrolyte solutions, but the process is operated above breakdown voltage, which results in the formation of micro-arc discharge plasma channels. Therefore it is possible that the formation of coatings is mainly composed of substrate metal oxides and also complex oxides containing the elements present in the aqueous electrolyte solutions [19].

In recent years, various manufacturing methods and techniques have been developed to produce stronger open cell metal foam materials. In this study, the MAO process was carried out in order to have a hard and strong ceramic coated layer on the surface of open cellular Ti6Al4V alloy foam materials, which were obtained by using replication and powder metallurgy methods. The porous structure of the foam material samples was investigated with optical and scanning electron microscopy (SEM). In addition to that, the phase structure of samples was characterized with XRD and EDX analysis. To examine the effects of Micro-arc Oxidation treatment on the mechanical properties of these foam structures, compression tests were performed.

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Table 1
Chemical composition of Ti6Al4V powders (wt. %), [20].

Element	Al	V	O	Fe	C	H	N	Cu	Sn	Ti
ASTM 1580-1	5.5–6.75	3.5–4.5	0.2	0.3	0.08	0.015	0.05	0.1	0.1	Bal.

2. Experimental details

In the present study, the open cellular Ti6Al4V based foam materials which were produced via the replication and powder metallurgy methods were treated with the MAO process. The replication technique consists of the impregnation of a polyurethane sponge with metallic or ceramic slurry followed by a thermal process (sintering). In this study, the spherical shaped Ti6Al4V powders which were produced by using gas atomization method with an average grain size of 35 μm Ti6Al4V powders were used. They were supplied by Phelly Materials Inc. The weight percentage of chemical composition of powders complied with ASTM 1580-1 standard [20] is given in Table 1. The replication technique and powder metallurgy method are both used to remove of polymeric materials and binders and also to sinter the metallic skeleton.

Fig. 1. Samples of the open cellular Ti6Al4V alloy based foams produced via replication and powder metallurgy techniques.

In order to achieve open-pore cellular shaped metallic foam, the polyurethane foams containing porosity of approximately 30 ppi (pores per inch) as a starting material were used. Polyurethane foams were cut into rectangular blocks of approximately $40 \times 20 \times 20$ mm^3. To saturate metal powders to the surface of the polyurethane foam and to overlay metal powders on the surfaces of the foams, a solution consisting of polyethylene glycol (PEG) and carboxyl methyl cellulose (CMC) was used as a binder system. First of all, Ti6Al4V metal powders were incrementally added to the solution and then a mixing process was performed for 1 h. The temperature of the mixture obtained was raised from the room temperature up to 75 °C. Then, sponge surfaces were coated with metal powders by immersing polyurethane foams in the liquid mixture. The removal of the excessive metal powders of the sponge and the protection of the open cell structure were ensured by passing the sponges, of which the surfaces were coated with metal powders, through two rollers. After samples were dried at 125 °C for an hour, polyurethane foam and organic binders were removed from samples by evaporation at 450 °C temperature and in Ar–H_2 atmosphere for 30 min. By sintering the samples at 1350 °C temperature and in hydrogen medium for 3 h, Ti6Al4V based metallic foams with open porous cellular structure were produced. The specimens of Ti6Al4V based foams produced in these processes are shown in Fig. 1. The process of manufacturing the foam samples was described in detail in previous studies [8,9].

The Ti6Al4V based foam samples were cleaned with alcohol and washed in distilled water, before they were subjected to the MAO process. The MAO process equipment consisted of a bipolar pulsed AC power (100 kW) source, a stainless steel (301 L) container (tank) with a sample holder as the electrolyte cell, and a cooling and stirring system. The samples and the wall of the stainless steel container were fixed as the anode and the cathode, respectively. MAO coating system set-up and the connection of the foam sample are presented in Fig. 2. During the MAO treatment, the electrical connection wire must only be connected to the foam sample; it should be disconnected from the

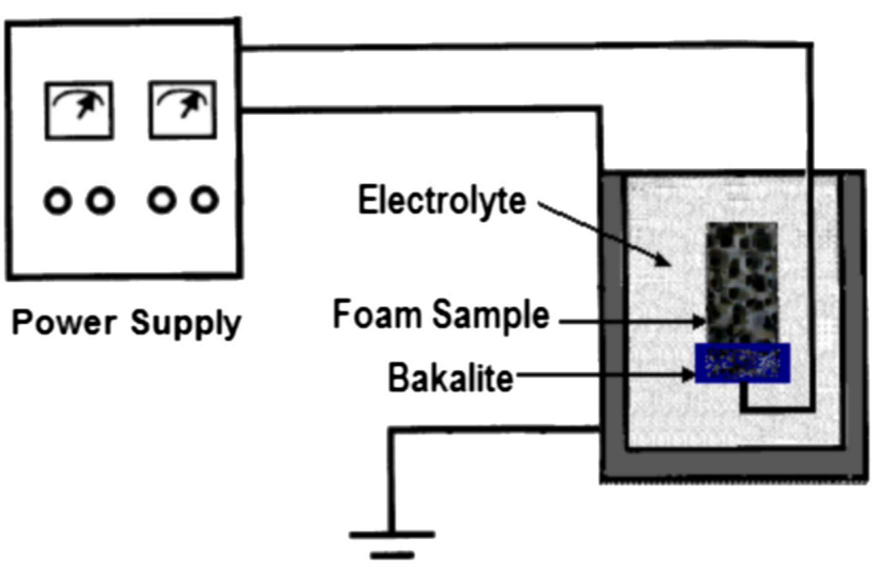

Fig. 2. Schematic illustration of MAO system set-up.

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