Using Lead as a Filler Material to Produce Porous Aluminum

أستخدام الرصاص كمادة أملاء لانتاج الالمنيوم المسامي

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Abstract

Porous materials are unique materials which can be used in light weight and strong structures. Few methods can be used to produce porous metals depending on the required degree of porosity, produced part size, nature of material and configuration. In this study, sintering technique was selected to produce porous aluminum using lead as a filler material. The whole process was conducted under vacuum environment at 500^oC and different soaking time to investigate and select the proper environment parameters. Results show that soaking time impacts significantly the resulting porous aluminum. Two hours of sintering at 500^oC and under vacuum environment was concluded as convenient parameters to produce controlled porous aluminum. The compacting process which used in producing green compacts was also investigated and it was found that 60MPa is the best selection of compacting pressure.

Keywords: Porous aluminum, powder metallurgy, sintering, porosity.

المستخلص

المواد المسامية هي مواد فريدة يمكن استخدامها في الهياكل القوية والخفيفة الوزن. هناك الكثير من الطرق التي يمكن استخدامها لإنتاج المواد مسامية اعتمادا على درجة المسامية المطلوبة، حجم القطعة المطلوب انتاجها، بالإضافة الى طبيعة المواد وتكوينها. في هذه الدراسة، تم استخدام تقنية التلبيد لإنتاج الألمنيوم المسامي باستخدام الرصاص كمادة وسيطة. أجريت العملية برمتها تحت بيئة تفريغ بدرجة حرارة تلبيد 500^oC مستخدمين فترات زمنية مختلفة للتلبيد لغرض استقصاء معايير التلبيد المناسبة. بينت النتائج بأن زمن التلبيد المستخدم له تأثير واضح على الألمنيوم المسامي المنتج. وقد تبين بان التلبيد لمدة ساعتين بدرجة الحرارة المذكورة يعطي نتائج جيدة لأنتاج المنيوم مسامي مسيطر على نسبة مساميته. كما تم استقصاء قيمة الضغط المستخدم لكبس مسحوق المعدن وتبين أن استخدام قيمة ضغط 60MPa هو الأمثل في عملية كبس العينات.

1- Introduction:

Porous metal is a solid metal containing significant volume fraction of open cells (interconnected pores). Such metals provide a significant combination of metallic behavior and properties inherent from their cellular structure. They have unique properties such as light weight, energy and sound absorbing in addition to incombustibility [1]. Applications of porous metals increased dramatically during last years in many engineering fields like automobiles, household goods, and the chemical industry.

Many metals can be used to prepare porous media but, as a general, porous materials are respectively expensive and therefore they represent a challenge if produced in the industrial scale. Nowadays, several porous alloys are commercially available such as aluminum, magnesium, copper, lead, nickel, and gold alloys [2]. Aluminum is the most commonly used to make porous metal with wide range applications in automotive industry. This important kind of porous metals can be easily recycled without any problems.

Many unique and unusually properties make porous aluminum suited for some important applications. It is isotropic porous material with low densities which are lie between 0.3 g/cm^3 and 0.8 g/cm^3 [3]. With this low level of density, porous metals with closed porosity may float in water. The heat and electricity conductivity of this kind of materials are in their lowest levels. Generally, strength declines with decreasing density so that, strength of the porous aluminum is lower than conventional dense aluminum.

The properties of porous metals depend on the preparation technologies and hence they may vary in a wide range. According to that, it is required to control the production parameters.

Banhart et al. (1995) succeed in preparation very homogeneous distribution porous aluminum of porosity level up to 90% using powder metallurgical techniques starting with powders of aluminum, aluminum-silicon alloy, zinc and lead [4].

Sharifi et al. (2014) used a direct foaming technique to produce low-cost, fast solidification, strong, and highly porous materials. Porous materials were produced from an aqueous suspension of ceramic powder. The subsequent stabilization of the structure was achieved by in-situ polymerization of organic monomers. They obtained higher strength magnitudes compared with the other conventional methods due to the dense strut sand walls structure produced [5].

Gerrard et al. (2011) prepared porous aluminum to be used as a core of cylindrical membrane by changing the surface chemistry of the metal via an electro-chemical process. They succeeded in producing porous aluminum with nano scale pours [6].

2- Methods of Producing Porous Aluminum:

There are several technologies which had been developed to produce porous materials. Among all of the cited technologies, a few processes and methods are suitable for producing porous aluminum in an industrial scale. Some of those methods start with aluminum liquid metal while the others use metal powder for the same purpose [4, 7].

2-1Porous metals made from metallic melts:

As a general, foaming methods which are start with metal melts are called direct foaming methods [8]. The most popular direct foaming methods are listed below:

a) Alcan/Norsk Hydro process:

In this process, porous metal is directly prepared by injecting gases into the liquid metal which is usually aluminum alloys. A suitable conveyor belt can be used for drawing off the resulting foam continuously. Additions includeAl_2O_3 or SiC can be added to the melt for the purpose of increasing the viscosity. After these additions, a gas (argon, nitrogen or even air) can be injected into the resulting melt by a specific device like an impeller. The product of this process will be porous sheet material with high level of porosity [9].

b) Alporas process:

A foaming agent can be added to the metal melt instead of blowing gas into it [10]. Increasing temperature will lead to a decomposition of the foaming agent and therefore, gas will be released. Using this method, Shinko Wire Company succeeded in producing porous aluminum under the registered trade name “Alporas” [11]. Briefly, calcium metal is added to the molten aluminum followed by a suitable soaking time to adjust viscosity. The continuous generation of calcium oxides under high temperatures will lead to increase viscosity. A blowing agent, usually titanium hydride (TiH_2) can be added after reaching to the desired viscosity. The melt will be started to expand slowly after releasing hydrogen (H_2) gas in the viscous melt and will gradually fills the foaming vessel. This expanded melt will turns to solid porous aluminum after cooling.

c) Solid-gas eutectic solidification (GASARS):

This method was earlier developed in the Ukraine[12].The main advantage of the GASAR process is the capability of producing high-density porous metals with a continuous casting process [13].This method benefits from the fact that gases are more soluble in metal melts than when metals are in their origin solid state. Hydrogen-helium mixture or hydrogen is used and diffused into molten metal's and after solidification;the gas will leaves the solution and as a result, pores will be generate within the solid steel body [14]. The main two parameters, pressure and rate of cooling, are chosen carefully to produce gas bubbles within the solid forming the required porosity [15].

d- Investment casting process:

Polymer foam can be used as a starting point to fabricate porous metals instead of directly foaming the metal itself [16]. For this purpose, open pores polymer must be processed firstly and then filled with a convenient material of a heat resistant. Then, polymer can be removed by drying and molten metal will be casted into the remaining open voids volume. The result will be porous metal similar to the original polymer foam structure.

e- Hollow Spheres:

In this method, metal melts are pouring over hollows spheres as a filler material to produce porous metals [17]. The hollow spheres can be prepared by placing solid spheres of a cheap material like polystyrene inside a suspension of the target metal and a suitable binding agent. Draining liquid will lead to generate green spheres which will then be sintered individually, compacting through powder metallurgy techniques [18], or casting in a metal matrix [19].

2-2 Porous metals made from powders:

As an alternative technique, powder metallurgy can be used to produce porous metals. It was developed for porous aluminum and still one of the most important methods of porous steel production. From this method, a highest relative porosity can be obtained up to 65% [20]. Thus; it was reported as a strong technique for many structural and engineering applications.

In powder metallurgy technique, metal powders are mixed firstly with a foaming agent. This mixture will be compacted inside a suitable dies before sintering. The metal content is brought to about 90% of its melting point and held there for minutes depending on the required porosity and the nature of the agent materials [21]. The resulting porous metal can be heat treated to optimize its crystal structure. Nowadays, filler materials are used instead of foaming agent giving graded porosity across the material [22].

3- A new Suggested Method:

Among many manufacturing’s processes, powder Metallurgy is preferred to produce net shape or near net shape products with minimum scrap losses. Porous parts such as filters can be made easily by this technology. As a general, it represents a sequence of processes which involves powder mixing, compacting, and sintering in addition to heat treatment processes. The principle of this technique depends on atomic diffusion and the necking phenomenon occurs between particles in the solid state [23]. Powder metallurgy is also refers to some related techniques like cold or hot isostatic pressing, powder forging, and injection molding. Alloys of unique properties can be produced by such processes but such techniques are preferred to minimize porosity instead of maximize it. Sintering technique was selected in this study to prepare porous aluminum using lead as a filling material. It is well known that lead has a low respectively melting point which is about 327^{o}C. The boiling point for this element is about 1749 ^{o}C but it decreases dramatically under vacuum environment due to its low vapor pressure. This fact will be very helpful to produce the required porous aluminum. Lead can be mixed with aluminum and removed later during sintering under vacuum environment. Sintering can be conducted under (6.7E-2) Pa at which lead will evaporate at temperatures less than 500^{o}C.

4- Experimental Procedures:

Aluminum powder with irregular shape of a purity of (99.9) and a mesh of (270) was mixed with lead powder of the same purity and mesh size. The similarity of mesh sizes of the mixed powders will minimize possibility of segregation after mixing. Thus, it is expected that the porosity will be homogeneous across the bulk volume of the produced porous aluminum. The prepared mixture contained 70%wt Al and 30%wt Pb. Mixing process was achieved by using the rotating type mixer shown in (Fig.1) for three hours. The mixture was compacted under 50MPa inside a uniaxial steel cylindrical die of 10mm diameter (Fig.2) with the aid of a hydraulic press device.

Fig.1: The mixing device used to mix powders.

Fig.2: The steel cylindrical die used to prepare green compacts.

Sintering was conducted inside a furnace under vacuum environment (Fig.3). A temperature of $500^{o}C$ was selected to conduct sintering which represents about 75% of the aluminum melting point. It can be noted from Fig.4 the schematic diagram of the sintering process which was based on during this study.

Fig.3: The furnace of vacuum environment used to sinter samples

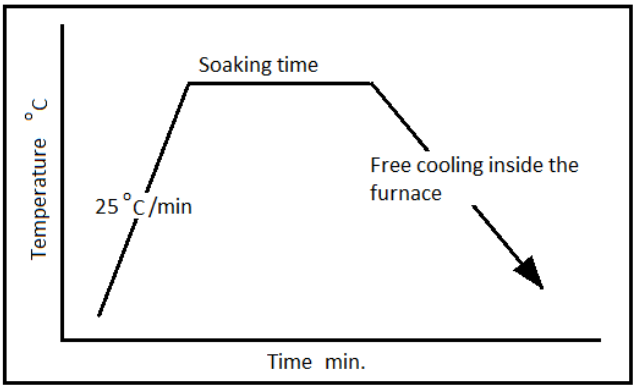

Fig.4: The schematic diagram of the sintering process

Ten samples were prepared with different soaking time (Fig.5). This was to investigate the effect of time parameter on the porosity of the prepared samples. The selected soaking time was varied from 15 to 150 minutes with an increment of 15minutes.

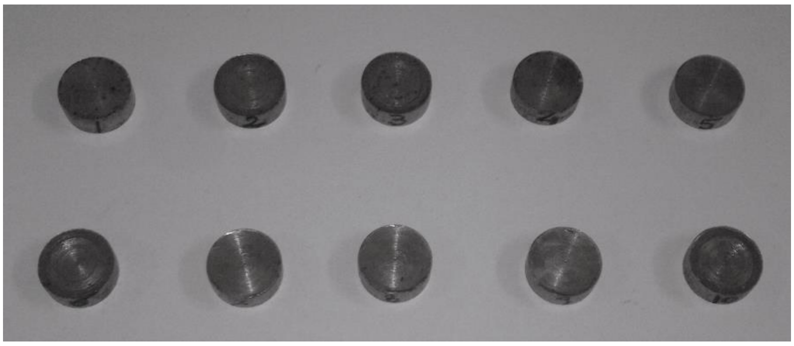

Fig.5: The ten samples sintered during the study.

The density and porosity of the sintered samples were measured according to ASTM, B 328 – 96, standard. According to this standard, density can be determined using equation (1) while equation (2) can be used to determine the Porosity [24]:

$$D = \left(\frac{A}{B-F}\right) D_w \text{----------------------------------} \quad (1)$$

$$P = \left[\frac{B-A}{(B-F)*D_o} * 100\right] D_w \text{----------------------} \quad (2)$$

Where:

A = mass of oil-free specimen in air, g.
B = mass of oil-impregnated specimen, g.
F = mass of oil-impregnated specimen in water, with mass of the suspension wire tared, g.
D_w = density of distilled water, 1 g/cm^3.
D_o = density of the oil, 0.85 g/cm^3.
D = density of the sintered samples, g/cm^3.
P = interconnecting porosity by volume, %.

A comparison was made among the sintered samples to make a decision about the required soaking time for the best values of density and porosity.

On the other side, five green compacts were prepared using different compacting pressure 30, 40, 50, 60, and 70 MPa to investigate the optimum selection of the required compacting pressure. All of these samples were sintered for two hours at 500^{o}C under vacuum environment and tested by a compression test machine of WDW-200E type.

5- Results and Discussion:

The density and porosity of all ten sintered samples were measured using ASTM, B 328 – 96, standard with the aid of the evacuating densitometer apparatus shown in (Fig.6).

Fig.6: Evacuated densitometer apparatus.

The results of the measured porosity show that the soaking time used during sintering process play a very significant role in producing porous aluminum. Increasing soaking time led to decrease in the final porosity due to diffusion of aluminum particles up to about 60 minutes. During this range of time, diffusion process affected porosity of the sintered samples more than lead evaporation effects. After this certain extent, the diffusion drag forces will decrease and porosity, in turn, will increase due to increasing in evaporation of lead content (Fig. 7). This increasing in porosity will continue till about two hours of soaking time after which it will lose its increasing intensity because most of lead content will be evaporated.

Further increasing of soaking time during sintering may lead to decrease the overall porosity of the products [25]. According to that, soaking time parameter must be optimized to minimize the overall energy consumption and furnace maintenance costs.

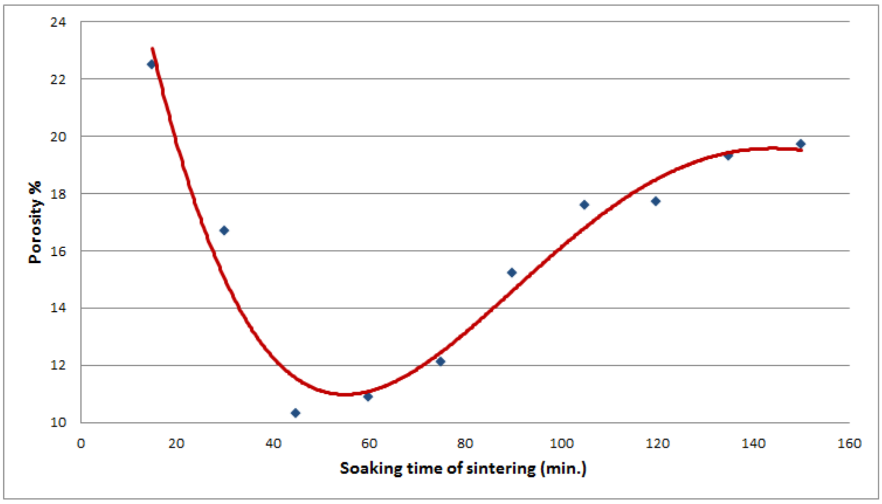

Fig.7: Effect of soaking time on the final porosity.

Figure (8) illustrates the results of the apparent density for samples prepared with sintering process. It is clear that the density of the samples which were sintered with a soaking time more than 120 minutes had the lowest densities. This result supports the previous results of the porosity measurement.

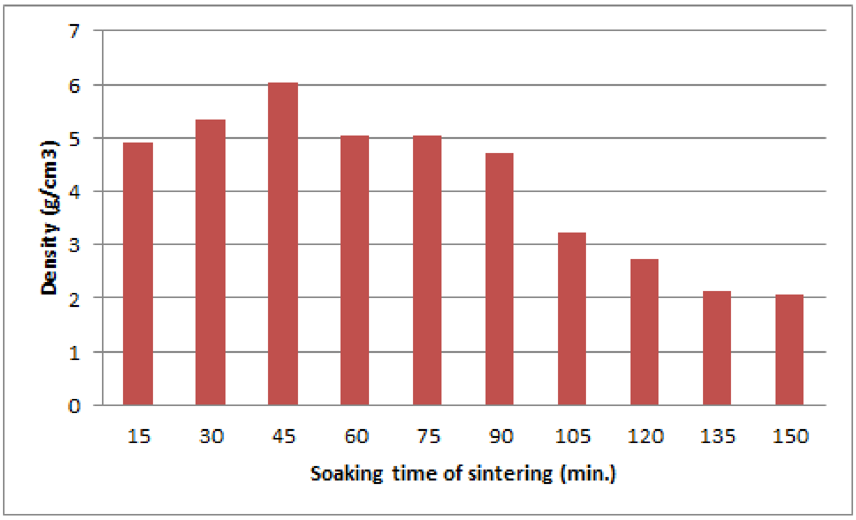

Fig.8: Effect of soaking time on the final density.

The sample which is sintered using 120 minutes as a soaking time during sintering was selected to be tested by an electron microscope device. This was to show the resultant porosity by scanning the outer surface of the sample (Fig.9). A magnification factor of 500 was used to take a snap shot for the surface of the selected sample. The porosity distribution over the entire area in (Fig.9) not only improve the succeed of the suggested method of producing porous aluminum, but also improve that three hours of powder mixing is enough since the produced porosity was homogeneous across the entire area shown.

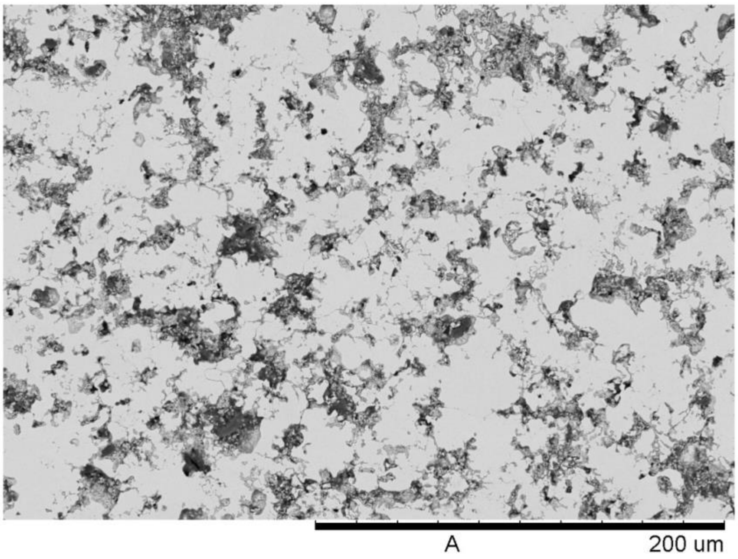

Fig.9: Electronic microscope image for sample sintered with two hours soaking time.

Results of the compression test are shown in (Fig.10). It represents the stress-strain diagrams for the five samples which there green compacts were prepared with 30, 40, 50, 60 & 70 MPa. It was clear that increasing the compacting pressure during preparing green compacts play a significant factor in improving the mechanical properties of the final sintered samples. The densification has a substantial dependence on the green density. According to that, there is a direct relationship between the mechanical properties and the compacting pressure used in preparing green compacts. Increasing this compacting pressure lead to increase the diffusion rate during sintering process and as a result increase the ultimate strength of samples. Further increasing in compacting pressure may create cracks in powders particles and this will affect inversely the final mechanical properties of the sintered samples. The optimum compacting pressure was found to be 60 MPa and sample which its green compacts were prepared under this value of pressing were gain highest strength around 90 MPa as shown in (Fig.10).

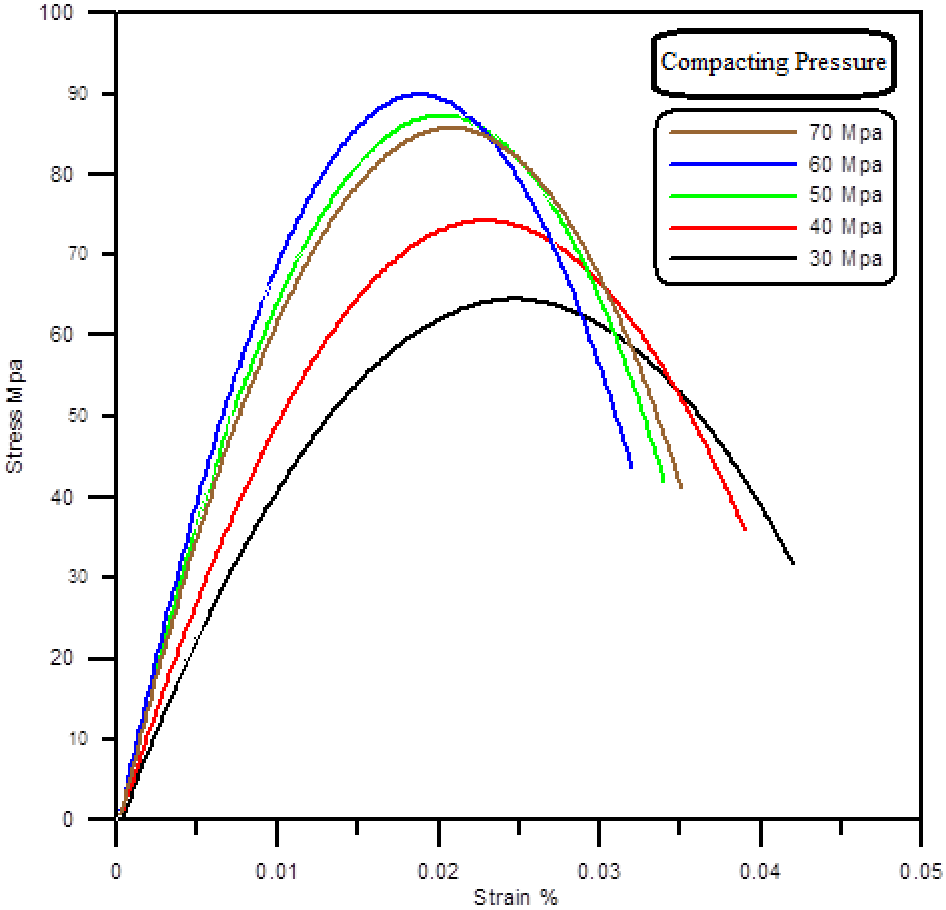

Fig.10: The compression stress strain diagrams for the tested samples.

6 Conclusions:

The use of lead as a filler material to produce porous aluminum represents a new suggested technique. It is simple method with low cost and good ability to control the overall porosity for the products. It is well known that the pressure used in producing green compact directly affected the overall porosity but unfortunately it inversely affected the diffusion during sintering. By the use of this new method, the final porosity can be easily controlled by selecting the proper percentage content of the transient materials. About eighteen percent porosity can be obtained using 30wt.% of leads powder in the green compacts. It is expected that the use of more than this weight percent of lead powders will cause an increasing in the final porosity.

It was observed that the use of about two hours is very convenient to produce porous aluminum under a vacuum environment with maximum sintering temperature of 500^{o}C. The interval of soaking time between 15 and 30 minutes give high porosity products but, unfortunately, with less diffusion and therefore it is expected that the samples within this interval of time are not strong enough and there will be still a quantity of a not evaporated lead element.

Green compacts can be prepared under 60MPa compacting pressure. The diffusion during sintering process will be better and hence, there final strength will be highest.

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