Advanced Materials Research
ISSN: 1662-8985, Vol. 879, pp 139-143
doi:10.4028/www.scientific.net/AMR.879.139

Online: 2014-01-16

The Effect of Sintering Temperature on Physical Properties of Sintered Inconel 718 for Potential Aerospace Industry Application

Nurhaslina Johari[1, a], Rosdi Ibrahim[1,b], Mohamad Azmirruddin Ahmad[1,c], Muhammad Jabir Suleiman @ Ahmad[1,d], Abdul Rahim Abu Talib [2, e]

[1] Advanced Material Research Centre, SIRIM Berhad, Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park, 09000 Kulim, Kedah.
[2] Department of Kejuruteraan Aeroangkasa, Fakulti Kejuruteraan, Universiti Putra Malaysia, 43400 Serdang, Selangor.

nhaslina@sirim.my[a], rosdi@sirim.my[b], azmir@sirim.my[c], jabir@sirim.my[d], abrahim@eng.upm.edu.my[e]

Keywords: Metal Injection Moulding, Powder Inconel 718, Palm Stearin, Polyethylene, sintering temperature.

Abstract. The most demanding high temperature application requires nickel-based super alloys, named Inconel 718 (IN718) is a precipitation hardenable nickel chromium alloy containing significant amount of iron, niobium and molybdenum along with lesser amounts of aluminium and titanium. The development of IN718 for metal injection molding was already proposed to provide increased resistance to distortion during and prior to debinding. This paper reports on the effects of sintering temperature on physical and mechanical properties of IN718 alloy. IN718 powder (60 vol%) with binder formulation (40 vol%) consists of polyethylene (PE) and palm stearin (PS) were mixed homogeneously and injected to produce green compacts. The binders then was removed and sintered at 1100 °C and 1200 °C for 8 h respectively. During sintering, the debound part is heated, which is allowing densification of the powder into a dense solid followed by elimination of pores. The sample sintered in vacuum condition at atmosphere 10^{-5} mbar whereby samples sintered at 1100 °C, show the density of 6.806 g/cm^3 compared to samples sintered at 1200 °C is 8.186 g/cm^3. Super alloy sintered at 1200 °C exhibited better densification rate with lower porosity. The preliminary results indicate that super alloy can be used in the MIM fabrication of nickel based super alloys to produce high-density sintered parts.

Introduction

Wrought components made from Inconel 718 have gained considerable acceptance in the manufacturing of high-performance turbine engine components. Many of these components are highly complex shapes which are very expensive to produce due to extensive machining. Casting does not yield material suitable for these applications because of segregation and microstructure inhomogeneity. The same is true of press and sinter powder Injection molding processes because of the shape complexity and dimensional tolerances which cannot be achieved without extensive machining operations

Powder injection molding (PIM) is an emerging technology for the cost-effective production of large numbers of small metals parts. PIM also has the ability to manufacture components with complex geometry and very close dimensional tolerances. In spite of the obvious cost advantage, PIM has not been implemented for the production of Inconel 718 turbine engine components. The reasons for this are because of the stringent mechanical property requirements for aerospace components, and the very limited engineering knowledge database of PIM Inconel 718 alloy [1-3].

Sintering is critical for determining the final quality of the part because high sintered density is comparative for good mechanical and physical properties and achieving full or near-full density has been major objective [4]. The objective of this research is to optimize physical and mechanical properties of Inconel 718 alloy on the effect of sintering temperature on sintered densities. The samples are then sintered in 2 different sintering temperature conducted in vacuum condition as to optimize the physical and mechanical properties.

Experimental Procedure

Pre Alloyed Inconel 718 spherical shape powder with chemical composition as shown in Fig. 1 is provided by Epson Atmix Corporation, Japan with tap density of 4.056 g/cm^3, apparent density of 1.00 g/cm^3 and pycnometer density of 8.19 g/cm^3, which can be adopted to determine the relative density of the sintered parts. The chemical composition of the powder given by the manufacturer is tabulated in Table 1. The 8 μm particle size distribution was determined using Cilas particle size analyzer and it can be seen that the powder had a relative wide particle size distribution which is desirable for efficient particle packing.

Table. 1. Chemical composition of Inconel 718 powder

Elements	Weight Percentage (wt%)
C	0.035
Si	0.39
Mn	0.23
P	0.014
S	0.006
Ni	52.60
Cr	19.17
Mo	2.96
Cu	0.01
Co	0.08
Al	0.18
Ti	0.71
Nb	5.27
Nb+Ta	5.27
O	4,900 (ppm)

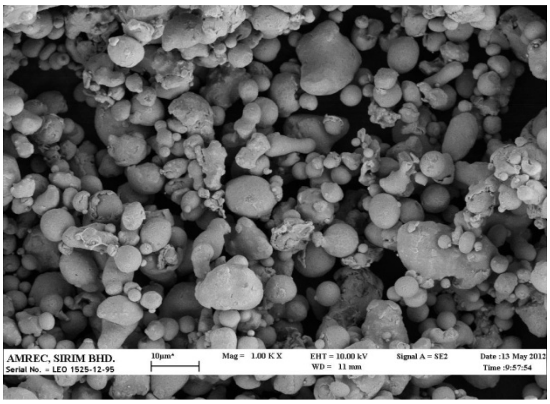

Figure. 1. A scanning electron micrograph of Inconel 718 powder

Thermoplastic materials can be derived from the palm oil. Thus, a novel binder is formulated and has been evaluated as a possible binder system. A binder systems are developed and the volume percentage of each binder composition is formulated; 60 vol % PE and 40 vol.% PS. In order to prepare the feedstock, the IN718 powder and the binder system are mixed homogenously at a ratio of 60/40 in a Winkworth MZ3 z-blade mixer at 160 °C for duration of 2 h.

The injection moulding process was performed using a vertical injection moulding at 180 – 200 °C with injection pressure of 6 – 9 psi. The debinding process is implemented through solvent extraction to remove over 2/3 binder systems. The solvent extraction process was carried out by immersed the sample into heptane and held at 60 °C for 6 h. As for the thermal pyrolisis, the process is performed in a high temperature control atmosphere furnace (HTCAF) in the same cycle of sintering where the sample is heated until 500 °C in vacuum at atmosphere 10^{-5} mbar and continuously sintered with heating rate from 2 – 7 °C/min until reach between 1100 – 1200 °C. The sintering condition is tabulated in Table 2.

Table. 2. Sintering condition of Inconel 718

Sintering Condition	Sintering Temperature (°C)	
	1100	1200
Sample	Sample A	Sample B

Result and Discussion

Thermal analysis

Table 3 shows the melting and evaporation temperature of PE and PS which measured using simultaneous thermal analysis (STA). From result, the melting and evaporation temperature will give the indication of designing the cycle for the removal of the binder system.

Table. 3. Melting and evaporation temperature of each component binder system

Binder Material	Melting Temperature (°C)	Evaporation Temperature (°C)
PE	125.9	488.0
PS	54.2	436.5

Physical properties and microstructure observation

The sintering process is carried out under vacuum condition at atmosphere 10^{-5} mbar, with zirconia plate supporting the parts during sintering. The density of the sintered sample is measured by the Archimedes principle using a Shimadzu specific gravity meter. Every sample of 2 different sintering temperatures was measured and analyzed statistically. Fig. 2 shows the density of sample produced using palm oil binder system. The density of sample A is 6.806 g/cm^3 and 8.186 g/cm^3 for sample B which is the highest, stated differences of 1.38%.

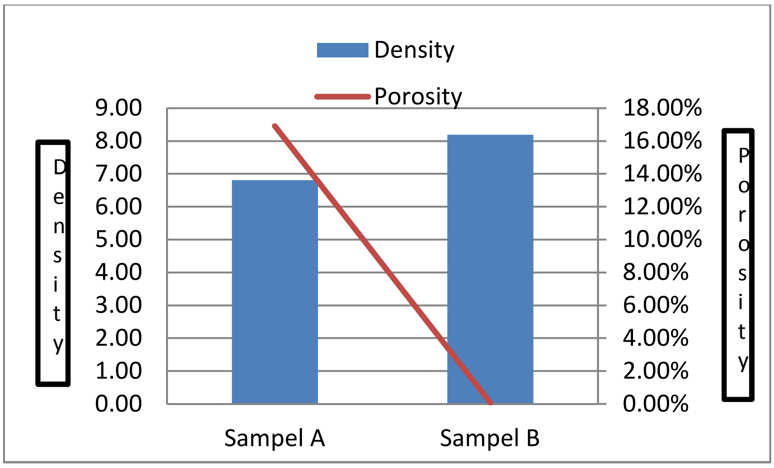

Figure. 2. Density and porosity properties of sintered Inconel 718

It proved that almost of the binder removed by solvent extraction and the remaining forms a gaseous product at thermal pyrolisis temperature as the binder evaporate and leaves pores among the powder particles. The volume of PS is fully melted during solvent extraction and totally removed after heating over than 436.5 °C which is over the PS evaporation temperature, as indicated in Table 3. According to Table 4, almost 16.90% pores occurs on sample A during removal of binder, 16.82% more than sample B and this situation based on the particle materials that unable to packed densely and fulfil the voids leaves by the binder. However, note that sample A stated the highest pores than sample B. Often a short period of time can cause various defects to form, such as fractures, low densification due to rapid release of the decomposition gas and effect of oxygen in uncontrolled atmosphere [5].

Uniform packing of particles has built the consequences on the size of the sample whereas the sample A shrinks to 3.02% and the percentage is among the lower compare to sampel B with 16.23%. This has indicated that particle which leaves after removal of the palm oil binder has better improvement in formation kinetics [7]. The porosity of the sintered part is strongly correlated with the density; therefore the porosity can be predicted from the density.

Table. 4. Physical and mechanical properties of sintered Inconel 718

Sample	Density (g/cm^3)	Porosity (%)	Shrinkage (%)
Sample A	6.806	16.90	3.02
Sample B	8.186	0.085	16.23

Fig. 4 (a) and 4 (b) shows the irregular pore structure leads to its low density of sintered part. It is thought that the porosity is reduced when the sintering temperature increased and this lead to the formation of grain. The grain boundary formation is a result of the grain coalescence process and though the orientation of the microstructure is slightly different, they essentially have a similar grain shape.

(a) Sample A

(b) Sample B

Fig. 4. Microstructure of sintered Inconel 718; Sample A (a) and Sample B (b)

Observations over a range of magnifications reveals that increasing temperature has significantly improved the homogeneity of the microstructure, specifically the pore size is reduced and the grain are more evenly distributed. The mechanical properties of sample A compare favourably with higher temperature of 1200 °C but fall short of the porosity values. However, minor surface flaws and the sintered surface texture may have constrained the texture of the specimens [6]. The high densification of sample B was achieved due to the particles which became interconnected signifying that under the condition of high temperature, grain displacement and plastic deformation occur which eliminating the pores, and therefore grain growth takes place along with the densification during the sintering process[5].

Conclusion

In this study, the optimum sintering temperature will be obtained in order to get the highest sintered densities with physical properties of Inconel 718 alloy and achieve the minimum requirement for standard Metal Powder and Industrial Federation MPIF-35.

References

[1] W. Track and W. Smarsly, "Injection Molding of High Temperature Materials," (Paper presented at the '93 Powder Injection Molding Symposium, Boulder, Co. Oct 1993), 4-6

[2] J. J. Valencia, T. McCabe, K. Hens, J. O. Hansen, and A. Bose, "Microstructure and Mechanical Properties of Ally 625 and 718 Process by PIM". Edited by E. Loria, TMS.

[3] R. Scheemes, J. R. Spirko, and J. J. Valencia, "Powder Injection Molding of Inconel 718 Aerospace Components" (Advanced Particulate Materials and Processes Conferene, West Palm Beach, FL, MPIF

[4] The Engineering Society for Advancing Mobility Land Sea Air and Space International, Aerospace Material Specification (AMS 5662G, Jan 1993).

[5] Hu Youhua, Li Yimin, He Hao, Lou Jia and Tang Xiao: Rare Metal Materials and engineering 39 (5) (2010) p. 0775-0780

[6] P. A. Davies, G. R Dunstan and A. C. Hayward: Powder Metallurgy World Congress & Exhibition. Shrewsbury: European Powder Metallurgy Association 2004 6

[7] Davies, P. A, Dunstan, R. Howells, R. Hayward, A. C: Advanves in Powder Metallurgy and Particulate Materials 8 2003 p. 8-12