



Advanced Materials Manufacturing & Characterization

journal home page: www.ijammc-griet.com



Application of Age Hardening Process to AA2011 Powders Produced by Oil Atomization Method

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ARTICLE INFO

Article history:

Received 16 Nov 2012

Accepted 26 Dec 2012

Keywords:

Powder metallurgy,
oil atomization,
age hardening

ABSTRACT

AA2011 aluminium-alloy powders were produced in an atomization unit, which was previously designed and manufactured, by using the oil as atomization fluid. Negative influence of oxide amount on the produced parts was reduced compared to water atomization method. Test specimens were produced by pressing the powders into the mold. In addition, age hardening process was applied to these specimens and comparisons were made with the parts produced by rolling process. The results showed that there was a significant difference in the hardness values depending on the time.

Introduction

Part production by Powder Metallurgy (PM) is commonly used and it has become an alternative to the classical processing methods. High quality powders have to be used in order to fabricate the materials by using PM method. Production of metal powders by atomisation technique has an important place in the present time. In the literature, there are three types of powder production methods such as water, inert-gas and air atomisation [1,2,3,4,7]. Gas and water atomisation, which are also called two fluid atomisation, are generally preferred for the production of high capacity powders [5]. However, there are certain limited properties of these powders produced by gas and water atomisation methods. For example, metal powders take the oxygen from the water, and oxygen percentages in the Al, Fe, Ni, Co and Cr alloys would become more than 1000 ppm. For this reason, in case of the usage of the powders produced by the water atomisation method containing high percentage of the oxygen, the notch impact strength of the produced parts decreases [1]. However, the oxygen rate in the inert-gas atomisation is lower than that of water atomisation. On the other

hand, the cost of the gas becomes an important factor if argon and helium were used as inert-gas. The oxygen percentages in the metal powders produced by certain atomisation techniques are given in Table 1. In this study, the oil atomisation method was used instead of water in order to reduce the oxide amount in the produced powders.

Table 1. The oxygen amount in the 125/45 μm powders of tin and AA2011 alloy

Metal	Atomisation	Oxygen amount after	Literature
AA2011	Oil	480	This study
Al	Water	6000	Dunkley[5]
Sn	Water	620	Dunkley[9]
304 L	Water	2000	Dunkley[9]
316 L	Water	2600	Dunkley[9]
Fe	Water	4855	Dunkley[9]

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- Doi: <http://dx.doi.org/10.11127/ijammc.2013.02.008>

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Cu	Water	387	Dunkley[9]
Ni	Water	645	Dunkley[9]

Oil properties used in the oil atomisation process must satisfy the following characteristics [17]

1. Low viscosity at the room temperature
2. Low ignition temperature
3. No poison effect (does not contain dioxin)
4. Cheap and easily obtainable
5. Must not lose its qualification during the atomisation and must be reusable
6. Low sulphur percentage if it was used in the atomisation of the sulphur effected alloys

KainerveMordike stated that the oils used for steel hardening was suitable for oil atomisation [6]. The metal powders after the atomisation process contains 2-3% of oil and this oil have to be removed (degreasing process) before using the powders. Moreover, there must not be any residues on the powder surfaces and the micro structure of the powders must not change, and also the oxigen rate must not increase after the atomisation process. In this study, Shell Voluta F (quenching) oil, which satisfied the all features mentioned above, was used.

In the atomisation process, tandish nozzle diameter (liquid metal beam diameter) is one of the most important parameters affecting powder grain size. Generally, previous studies reveal that avarage grain size decreases as nozzle diameter increases [7, 14, 15]

The aim of this study was to produce the powders of AA2011 aluminium-alloy by oil atomization method. Water-atomized powders generally are quite irregular in shape and have high surface oxygen contents. Gas atomized powders generally are more spherical or rounded in shape. Gaz-atomized powders have lover oxygen contens. If atomized by inert gas, oxide will be decreased[1]. Oil atomization is between water and gas atomization.

Materials and Method

Degreasing of the produced powders, sifting and metal alloys used in the experiments

In this study, analyse of the oil, used for the atomisation process, was carried out at the TUBITAK instrumental analyse laboratory. The chemical composition of this oil is given in Table 2.

Table 2. The chemical composition of the Shell Voluta F oil(%weight)

C	H	N	S	O
83.89	14.34	0.113	0.744	0.464

Viscosity (cSt/100 °C) : 4.4

Degreasing of the produced powders was performed at two stages. Firstly, the oil was cleaned by using the solvent. Fort this purpose, industrial thinner was used once at every time and, the oil was cleaned for four times. In the second stage, the previously cleaned powders were cleaned again in the ultrasonic cleaning instrument for different time periods such as 5 min, 15

min and 20 min. Then, the extraction process was applied for four ours with Soxhlet device by using petroleum ether such that it made siphon for every four hours.The measured oil amount in the first stage was found to be 0.2%. In the second stage, which was ultrasonic cleaning process, the oil amount reduced to around %0.022. Moreover, sifting analyses and fluidity measurements were performed by using the powders which were cleney by these methods. For sifting analyse, the powders were preperad by the sampling method as described in ASTM B215 and ISO 3954, and the sifting analyse was performed in accordance with ASTM B214 and ISO 4497 [7,8]. In the sifting process, since the appearent density was lower than 1.5g/cm³ as described in the standard, the weight of the AA2011 powders were choosen as 50g and then the sifting process was applied for 15 minutes. The powders weight accumulated at the each strainer was weighted in the 0.01g precision.

In the experiments, AA2011 alloy was used and the chemical composition of this alloy, which was determined by spectral analyse, is given in Table 3.

Table3. Chemical composition of the tested metal and alloy. (% weight.)

Alloy	Fe	Si	C	Mn	Mg	Zn	Ti	Cr	Al	Others
AA2011	0.2	0.2	5.80	0.033	0.035	0.016	0.019	0.002	93.52	0.10

Atomisation unit (Atomisator) used for the tests

A test apparatus was designed for the production of the metal powders and an atomization unit was manufactured, as seen in Figure 1. The technical specifications of this atomization unit can be seen in Table 4.

Table 4. Technical specifications of the oil atomization unit

Unit	Feature
Oil tank:	1000 lt
Type of oil pump :	Gear type
Oil pump:	Max. pressure: 4 MPa (0-4 MPa adjustable) Motor power: 20 kW
Atomisation tank:	1200x1200x1400 (mm)
Tundish liquid metal beam:	Diameter 3 mm
Suction pipe:	1 1/2" (steel pipe)
Delivery pipe:	1 1/4" (Seamless steel pipe)
Nozle number:	2
Nozle type:	V-Flatt jet (open type)
Jet length and angle:	Adjustable
Tundish:	Graphite pot
Tundish liquid metal:	Volume 0.5 lt
Furnace:	6kW+ 6kW(Controlled by two different power switch)
Furnace and tundish:	Together
Temperature control:	±5 °C
Powder reservoir:	storage 300x500x250 (mm)

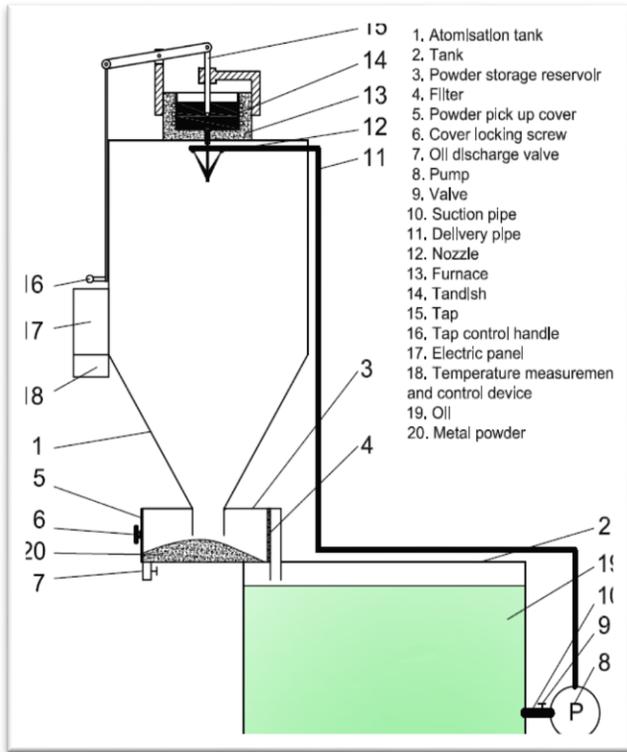


Figure 1. Schematic Picture of the atomisation unit (Atomisator).

Fabrication of the parts from the AA2011 alloy powders produced by oil atomization and application of age hardening process

AA2011 aluminium alloy powders were produced by using the manufactured atomization unit previously mentioned and given in Figure 1. 10 gram produced powders were cold pressed into the 15 mm diameter cylindrical mold under 14 ton and then it was taken in an aluminium holder. It was heated to 520°C for half hour and then hot forging process was applied. After the hot forging process, the holder was removed by cutting and the fabricated part was polished by sanding. Then, age hardening process was applied to the produced parts. The dimensions of the AA2011 alloy and the specimen produced from the powders were made the same in order to quenching under the same conditions and to compare the hardness. After heating up to 540°C in a furnace for two ours, the test specimens were cooled in the water. Additionally, hardnesses of the test specimens were measured periodically by putting them into the annealing furnace at 150 °C.

Results and Discussion

Powder particle distribution of the fabricated AA2011 alloy and SEM images of the powders are given in Table 5, Figure 4 and Figure 5, respectively. Moreover, the Brinell hardness of the part, which was fabricated from the produced powders and the rolled AA2011 alloy, were 66 and 76, respectively. Moreover, after age hardening and dissolution process, hardness values of the test specimens were found to be 74 BSD for rolled part, and 65 BSD for forged part.

Hardnesses of the test specimens were measured periodically by putting them into the annealing furnace at 150 °C, as seen in Figure 2. As seen from these figures, the increase rate of the rolled part was greater than the part produced form the powders. Furthermore, the hardness values of the test specimen produced by hot forging were found to be lower. The reason for this was that the macro hardness of the porous PM part was low and the heating was slower.

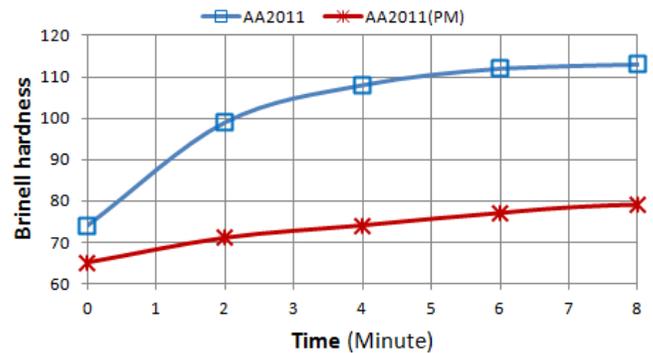


Figure 2.. Age hardening curves of the rolled part and the part fabricated by hot forging of AA2011 powders (Logaritmic scale).

Table 5. Sieve analyse results of the AA2011 alloy powders produced at 3.0 MPa

Test number	: 26	
Jet length	: 75 mm	
Nozzle number	: 2	
Nozzle angle	: 30°	
Over heating	: 120 °C	
Liquidmetal temperature	: 770 °C	
Tandishliquid metalnozzle diameter	: 3 mm	
SIEVE ANALYSE		
Sieve opening (µm)	Powders distribution %weight	Cumulative powder %
1000	7.24	100.00
-1000/710	8.04	92.76
-710/500	8.15	84.72
-500/355	9.00	76.57
-355/250	11.00	67.57
-250/180	14.92	56.57
-180/125	17.17	41.65
-125/90	13.28	24.48
-90/45	7.68	11.20
-45	3.52	3.52



a)



b)

Figure 4. Microstructure of the powders of AA2011 alloy produced by oil atomisation. a) -355/250 b) -180/45.



a)



b)

Figure 5. Microstructure of the powders of AA2011 alloy produced by oil atomisation. a) -90/63 b) -63/45

From the SEM images of the produced powders it was observed that grain shapes of the powders were different from that of powders produced by water atomisation method having irregular structure. In addition, although there was porosities in the coarse grained powders, porosity decreased in small grained powders. The morphologies of the powders of AA2011 alloy produced by oil atomization method are presented in Figure 4 and Figure 5. It could be observed from these morphologies that the powders are twiggy, columnar and sometimes spherical in shape.

In order to examine the properties of the part, test specimens from the AA2011 powders were produced by hot forging method. In addition, in order to compare the produced part and rolled AA2011 alloy, the parts were cut into prismatic pieces of 40x60x6 mm. Then, after heating up to 540 °C and cooled with water, they were aged at 150 °C. As seen from Figure 2 and Figure 3, hardness of the rolled part was greater than that of the part produced by PM method and it increased rapidly in the first 8 minutes. It is known that porosity can be formed in PM production technique. These porosities causes both the thermal conductivity and and macro hardness of the alloy to decrease. For this reason, lower macro hardness and higher ageing time of the produced specimens in this study can be attributed to the porosity.

According to the test results, oxide amount of the produced powders was found to be lower than that of the powders produced by water atomisation method. This lower oxide amount improves the part quality and especially notch impact strength.

Ambient temperature of the oil affects the cooling rate of the oil atomisation, and this cooling rate was between cooling rates of the gas and water atomisation. For this reason, bigger oil tanks have to be used especially for mass production. Test results indicate that atomisation pressure in the oil atomisation is the most important factor affecting the powder grain size.

Oxidization tendency of the aluminum alloy is more than some metals such as tin [1]. One of the important parameters in the atomisation process is the extreme heating above the melting point or liquidus temperature. In this study, extreme heating amounts was choosen as both 120 °C and 200 °C. These heating amounts were compared. Avarage grain size decreased when extreme heating amount increased. This is confirmed by some previous researchers [10, 11, 12].

In this study, atomisation process carried out in the air ambient, the oxigen amount in the aluminum alloy was found to be small, but it was somewhat higher than the results of Dunkley [5].

In our study, oil atomisation of the aluminum alloy was performed by increasing the oil fow rate. In the lower oil flow rates, there could be combustion hazard above the 500 °C. Accordingly, the protector has to be operate at the gas environment. This protector gas environment would reduce the oxidation.

Conclusions

According to the test results, oxide amount of the produced powders was found to be lower than that of the powders produced by water atomisation method. This lower oxide amount improves the part quality and especially notch impact strength. Bigger oil tanks have to be used especially for mass production. Furthermore, test results indicate that atomisation pressure in the oil atomisation is the most important factor affecting the powder grain size. Besides, average grain size decreased when extreme heating amount increased. In this study, the oxygen amount in the aluminum alloy was found to be small due to performing the atomisation process in the air ambient. It is recommended that one operate at the protector gas environment due to combustion hazard above the 500 °C. This protector gas environment would reduce the oxidation.

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