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EFFECT OF SHOT PEENING PROCESS ON ALUMIX 431 POWDER MATERIALS

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ABSTRACT: *In this work, Alumix 431 metal powders have been chosen for study due to widely used in the industrial applications. First, Alumix 431 powders were pressed at 400 MPa pressure and room temperature (RT). Then, pressed specimens were sintered at 600 ºC and 620 ºC temperatures for 1h separately. In order to examine effects of sintering operation to density, densities have been measured in per different temperature. After sintering operation, a group of specimen was shot peened in 12A and 16A intensities. To investigate mechanical properties of sintered and shot peened Alumix 431 powders, tensile and fatigue tests were performed.*
Keywords: *Powder metallurgy, Alumix 431, Sintering, Shot peening, Fatigue strength*

BİLYALI DÖVME İŞLEMİNİN ALUMIX 431 TOZ MALZEMELER ÜZERİNDEKİ ETKİSİ

ÖZET: *Bu çalışmada, endüstriyel uygulamalarda yaygın olarak kullanılan Alumix 431 tozları seçilmiştir. Alumix 431 tozları 400 MPa basınç ve oda sıcaklığında sıkıştırılmıştır. Daha sonra, sıkıştırılan numuneler 600 ºC ve 620 ºC sıcaklıklarda 1 saat sinterlenmiştir. Sinterleme işleminin yoğunluğa etkisini araştırmak için, sinterlenmiş numunelerin yoğunlukları farklı sıcaklıklara göre her biri ayrı olarak ölçülmüştür. Sinterleme işleminden sonra, bir grup numuneye 12A ve 16A yoğunluklarında bilyalı dövme işlemi uygulanmıştır. Sinterlenme ve bilyalı dövme yapılmış Alumix 431 toz malzemelerinin mekanik özelliklerini incelemek için çekme ve yorulma testleri yapılmıştır.*
Anahtar kelimeler: *Toz metallurjisi, Alumix 431, Sinterleme, Bilyalı dövme, Yorulma dayanımı*

1. INTRODUCTION

Commercially available aluminum powder alloy compositions consist of blends of atomized aluminum powders blended with powders of various alloying elements such as zinc, copper, magnesium and silicon. The Alumix 431, which is 7xxx series, is one of the aluminum alloys of the most common heat-treatable grades and been used in industrial applications. The Alumix 431 based on additions of zinc, magnesium and copper is a high strength aerospace alloy. The 7xxx series alloys have the highest age hardening response of all the conventional aluminum alloys. Zinc provides the greatest contribution to the age hardening of aluminum without recourse to costly non-equilibrium techniques such as rapid solidification. Copper is added to these alloys principally to improve resistance to stress corrosion cracking. Magnesium, even at the 0.5% level, does impact on shrinkage in a positive manner reducing the oxide, allowing metal-metal contact at particle interfaces and facilitating diffusion [1-3].

Conventionally pressed and sintered aluminum powder metal parts have been available for many years. Powder metallurgy (PM) has been recently the subject of renewed attention because of the combination of the lightweight of aluminum and the efficient material usage of the PM process, which present attractive benefits to the perspective end users. The effect of manufacturing parameters of the PM parts, such as alloy compositions, density, sintering conditions, mechanical and thermal surface treatments and heat treatment, on the static and fatigue properties play an important role [3].

In modern technology shot peening has potential application in the engineering field from earth to space technologies. When advanced mechanical treatment technologies such as laser shot peening and low plasticity burnishing which are more expensive and time consuming compared, shot peening process has different application in the automobile, marine and aerospace vehicles in the race of high technology. The surface modifications produced by the shot peening treatment are (a) roughening of the surface; (b) an increased, near-surface dislocation density (strain hardening); and (c) the development of a characteristic profile of residual stresses [4, 5]. It has been recently indicated that shot peening is also an effective way of improving fatigue strength in PM parts [6, 7].

In this work, the effect of sintering and shot peening processes on Alumix 431 aluminum alloys was investigated. To determine the effect of sintering temperature and peening intensity on the mechanical properties, the tensile and fatigue samples were sintered and shot peened at various temperatures, times and in intensities separately. Moreover, the tensile and fatigue results for unpeened and peened conditions were evaluated and compared.

2. MATERIAL AND METHOD

2.1. Material

Material used in this study was Alumix 431® powder from Ecka Granules in Germany. It is a mixture of 7xxx series aluminum alloys. The chemical composition and particle size characteristics of Alumix 431 powders are given in Table 1. The specimens were compacted in a cylindrical die of 15 mm diameter to give compacts of about 15 mm in height, which has approximately a weight of 3.5 g with an accuracy of 0,001 g for static properties. This allowed good density distribution in the compact and reduced die wall friction, even though no lubricant was separately used.

Table 1. Chemical composition and particle size characteristics of the Alumix 431

Chemical Composition, % (Theoretical Density: 2,786 g/cm^3)					Particle Size Characteristic*				
Al	Cu	Zn	Mg	Lubri-cant	D_{10}	D_{50}	D_{90}	S_w**	Mean Value
89	1,5	5,5	2,5	1,5	54,8	107,2	193,1	4,7	118,7

*Dimensions are in µm, **S_w: The particle size distribution slope

2.2. Method

In this study, the components of powder (Al-5.5 Zn-2.5 Mg-1.5 Cu; elemental mixing is in weight %.) mixing is loaded into prismatic blanks which a die in sizes of 10x10x55 mm^3 as shown in Figure 1 and then cold compacted under 400 MPa pressure at room temperature (RT) using a single action press.

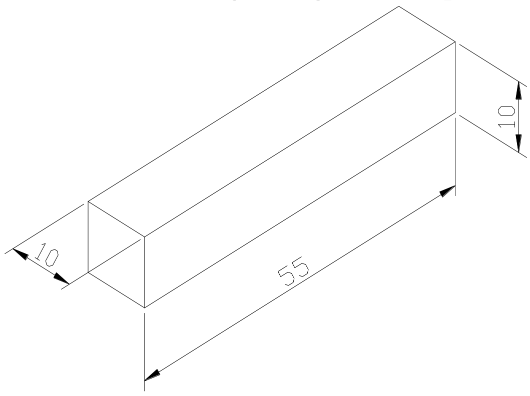


Figure 1. Compacted aluminum alloy

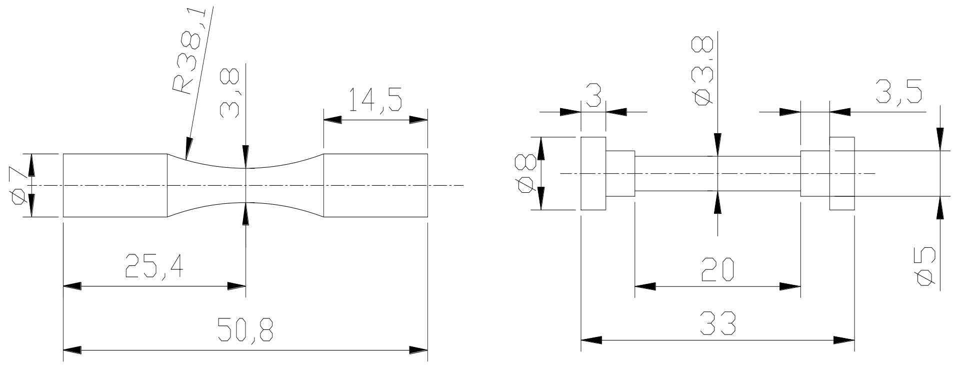
Sintering of materials was performed in an automatic controlled high temperature gas atmosphere tube furnace using Protherm Electrical Furnace, which is PTF 4/75/750 model, and can heat up to 1600 °C temperature. Eksi et al. stated that in order to determine the optimum sintering result, the specimens were sintered under five different sintering conditions and 620 °C was selected the best sintering temperature to produce the samples for tensile and fatigue tests since it resulted in high density [8]. They found that the best sintering temperatures were at 600 °C and 620 °C temperatures. Therefore, the specimens were sintered at two different temperatures that was at 600 ºC and 620 ºC. All specimens of pressed dies were sintered for 1 hour at 600 °C and 620 °C temperatures in groups of fifteen each in N_2 atmosphere, respectively. Temperature was increased by 5 °C/min until medium of furnace reached sintering temperature; and then specimens were kept in turn in these temperatures 1 hour for sintering operation. After that, furnace was closed and temperature was decreased by 5 °C/min until medium of furnace was reached room temperature (22 °C). While the specimens were cooling, the furnace was also running in N_2 atmosphere, which is protective gas. These operations were continued till medium of furnace was reached RT and afterwards, sintering process was ended up.

The density of sintered and green Al alloys was evaluated. Densities of green and sintered parts were measured by the Archimedes Principle (water displacement technique) using Precisa 320XT series for analytical and precision balances in Gazi University's Mechanical Research Laboratory in Ankara, Turkey. Pure water is used for measuring media at room temperature. Sintering conditions are given in Table 2. The sintered samples were conducted with machining operations and polishing operations using Computerized Numerical Control (CNC) turning lathe and metal polishing machine. Fatigue, tensile test sample dimensions are shown in Figure 2.

Table 2. Sintering conditions used in this study

Specimen	Atmosphere*	Heating rate, °C/min	Cooling rate, °C/min	Sintering temperature, °C	Sintering time, min
No.1	N_2	5	5	600	60
No.2	N_2	5	5	620	60

* N_2, dry, clean, dew point lower - 45 °C



(a) (b)

Figure 2. Dimensions of samples; a) Fatigue, b) Tensile (Dimensions are in mm)

There are many ways to improve mechanical properties of parts produced by PM like heat treatment, boronizing, and shot peening etc. The shot peening that was one of the most economic surface processes that applied to increase fatigue life of material. To evaluate unpeened and peened parts in respect to mechanical properties, 15 samples were sintered and after sintering operation, other 15 samples are shot peened in 12A and 16A intensities separately according to [9-14] to perform the best results using an air high-pressure type of equipment. The shot peening parameters used in this work are given in Table 3. The shot peening studies were carried out using IEPCO Micropeen-Peenmatic 2000S Machine in Laboratory of 1st Air Supply and Maintanence Center (1. Hava İkmal Bakım Merkezi Komutanlığı) in Eskisehir/Turkey.

Table 3. Shot peening parameters

Specimen	Material, sintering temperature	Peening intensity, A (mm)	Shot material, shot diameter (mm)	Peening air pressure, psi (MPa)	Peening time, second (s)
No.1	Alumix 431, 600°C	12 (0, 30)	Steel, S 110 (0, 27)	50 (0, 34)	15
No.2	Alumix 431, 620°C	16 (0, 40)	Steel, S 110 (0, 27)	50 (0, 34)	27

3. RESULTS AND DISCUSSION

In this study, sintering process was carried out at 600 and 620 °C temperatures. Compaction process was executed constant pressure of 400 MPa and at room temperature. First, after compaction process, green densities were obtained 2, 53 g/cm^3. Then, densities of sintered specimens were measured 2, 42 (No.1) and 2, 50 g/cm^3 (No.2) at 600 and 620 °C, respectively. Increasing sintering temperature causes higher density in sintered parts because of reducing pores. When pores reduce, particles are yielded and volume is decreased. Therefore, the density is increased. Densities of No.1 and No.2 samples are different despite of fact that temperature raises a small difference such as 20 ºC. Hence, No.2 has higher density than No.1. Besides, as comparison of theoretical and sintered densities, No.1 and No.2 have approximately 86%, 90% of theoretical density, respectively. Consequently, sintering density increased roundly 5% on account of increase of temperature. Results show clearly that the sintered densities under N_2 protective gas atmosphere were marginally lower the green densities even increasing sintering temperature. This is because of fact that the porosity was not completely eliminated, despite it was significantly reduced.

Al sintered powder parts were subjected to tensile and fatigue tests after sintering and shot peening process. All samples are symbolized for definition of samples according to conditions as shown in the Table 4. Tensile and fatigue tests were executed at room temperature using Instron® Machine with a controller Fast Track® 8800 series connected to a computer and a servo hydraulic.

Table 4. Symbols of material used in this work

A	material sintered at 600 ºC
B	material sintered at 620 ºC
S	only sintered material
P	shot peened after sintered material

To examine the static and dynamic properties of samples, tensile and fatigue tests were carried out. In tensile test, action velocity of Instron® Machine was taken v = 0, 3 mm/min as vertical movement and was kept constant during experiments. The tensile behavior of Alumix 431 material which was peened and unpeened was examined by conducting tensile tests on specimens of each type. As tensile tests indicate a little plastic region in accordance with characteristic of Alumix 431 powder because of fact that graphics of all tensile have slightly slope as horizontal as can be seen in Figure 3, extension at break were represented at maximum load. That is, the data for yield strength could not be obtained from tensile tests. Sintering and shot peening processes were gradually provided the density increases. The more density rise, the more tensile strength increases as stated in literature. Therefore, the Ultimate Tensile Strength (UTS) were indicated slowly increase in accordance with sintering temperature and shot peening intensity.

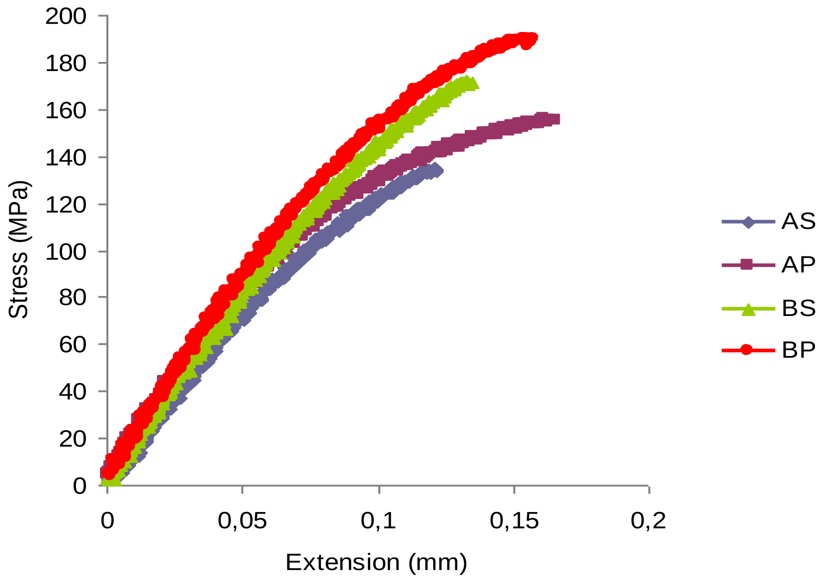


Figure 3. Comparison of tensile stress curves

Table 5. Characteristic tensile properties of parts

Conditions	Sintered Density, (ρ) g/cm^3	Young's Modulus (E), GPa	Ultimate Tensile strength (UTS), MPa	Strain (A), %
AS	2,42	36	132	0,24
AP	-	40	157	0,36
BS	2,50	46	170	0,57
BP	-	52	1 5	0,63

Fatigue tests were conducted using same way, too and results of these tests were plotted Nominal stress amplitude, $\sigma_{a,n}$ (MPa) versus Cycles to rupture, N_R (Number). Fatigue tests were performed in the axial load control which is more severe than bending under fully reversed loading (stress or load) ratio $R = \sigma_{min}/\sigma_{max} = -1$ which is sine waveforms using 15 specimens for the determination of each S-N (Wöhler) curve. The tests were carried out at the constant frequency of f = 10 Hz. One stress ratio was investigated on the unnotched (K_t = 1) specimens. All the tensile and fatigue experiments were carried out in the Materials Laboratory of Department of Mechanical Engineering of Cukurova University in Adana/Turkey.

For the result of axial fatigue tests, Wöhler curves were plotted correspond the greatest cycle values. The fatigue test machine including clamping of the specimen used in this investigation is seen in Figure 4. Average stresses in the interval of 30–

120 MPa were evaluated. In all tests, cycle number have been constant to be N_R = $2x10^6$ as boundary cycle number that proposed in literature and run-out was defined as no failure after $2x10^6$ fatigue cycles [15, 16]. The fatigue test results for unpeened and peened conditions were compared. As mentioned in literature, it was seen that shot peening improved fatigue life by about 10%, 15% using 12A, 16A intensities on No.1 and No.2 sintered specimens, respectively. Fatigue strength increased from 100 MPa for unpeened specimens to maximum of approximately 115 MPa for the specimens peened to 12A and from 105 MPa for unpeened specimens to maximum of approximately 120 MPa for the specimens peened to 16A at this the same as shown in Figure 5. It was thought that shot peening was improved fatigue strength because of compressive residual stress and peening intensity.

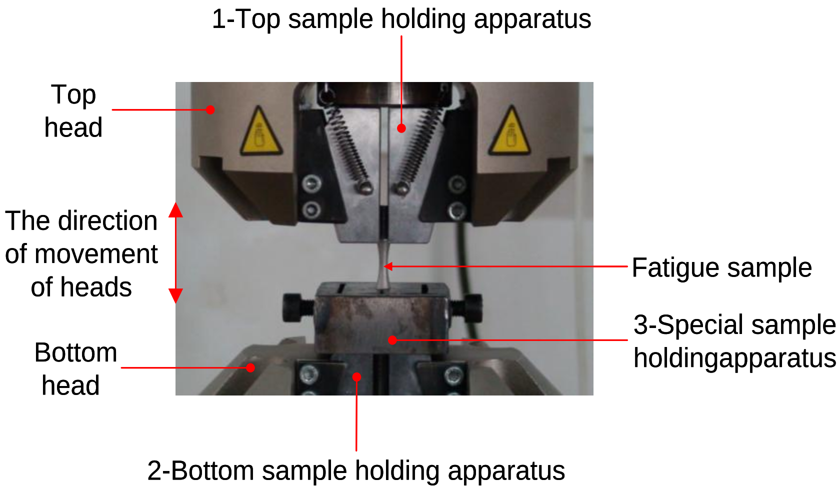


Figure 4. Set up of tensile and fatigue tests apparatus

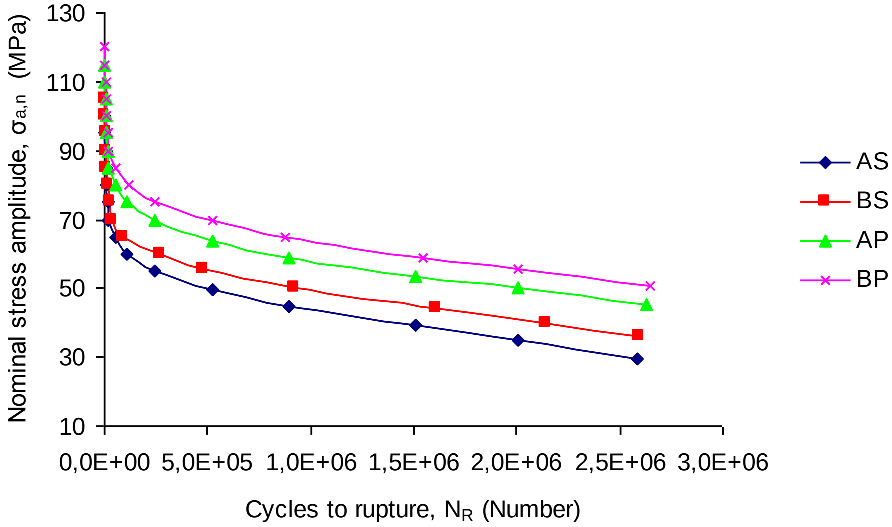


Figure 5. Comparison of S-N curves for all peened and unpeened specimens

4. CONCLUSIONS

The density measurements of Alumix 431 aluminum alloys sintered at 600 and 620 ºC have been performed and comparison of green and sintered specimens has been done. The results show that highest density has 2, 50 g/cm^3 on sintered specimen at 620 ºC, 400 MPa, RT.

The porosity reduced and structures became homogeneously with arising temperature. The density is affected directly reducing porosity. Shrinkage of pores was occurred due to decreasing of volume of sintered parts, and weight did not change. Thus, the density was increased. High density means that has high strength of sintered parts, and it is desirable feature with powder metallurgy because of fact that high density also affects mechanical properties like strength, toughness, and hardness etc.

Shot peening and sintering process were indicated positive effect on materials. Tensile strength increases because of fact that sintering temperature and peening intensity arises. For reason, Ultimate Tensile Strength was represented an increase between 132 and 185 MPa.

Fatigue stresses in the interval of 100-120 MPa have been tested. Shot peening gives a marked improvement in the fatigue strength over as the machined condition, with around an order of magnitude increase in cycle life. The effect of shot peening on the fatigue behaviour of Alumix 431 has been investigated. Shot peening has been found to offer a significant improvement in the fatigue life with 10% and 15% increases in the endurance limit of material in 12A and 16A intensities, respectively according to unpeened samples because of fact that shot peening causes increase of density of part.

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