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Full Length Research Paper

Improvements of dry sliding wear behaviour and mechanical properties in 2014 Al alloy by age-hardening

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In this study AA 2014 powder metal alloy was produced by using the vertical gas atomization method. In the post-production stage, by unidirectional pressure in the steel mould, the powders were converted into powder metal samples. The derived powder metal particles from the micro structural point were subjected to sintering process for 1 h at the temperature range of 550 and 620°C. Next, the samples were exposed to heat treatment at the temperature interval of 2 to 192 h in 500 and 600°C. For aging heat treatment, water quenching process post-solution treatment at 520˚C was applied to these samples. Afterwards, these samples were applied to aging process at 150°C on the condition of the range of 4 to 24 h, and up to 70% increase in hardness was determined. Finally, through an examination of dry fictional wear behaviours of samples processed at 550 and 600°C, oxide occurrence with increasing heat was observed to effect wear loss and wear loss was identified not to be linear as the distance raised.

Key words: Wear, age-hardening, 2014 Al alloy.

INTRODUCTION

Powder metallurgy is the process of producing metal powders and turning them into items by combining them under the mechanical and thermal influences. Nowadays, through powder metallurgy, particle production is very common and is increasingly becoming an alternative way to the traditional producing methods (Unlu et al., 2009; Eksi et al., 2007). Owing to the perfect characteristics of aluminium alloys as low density, high resistance, and high temperature and electrical conductivity, they are used in variational usages within a wide application range (Totik et al., 2004). These alloys are commonly applied in automotive and aviation industry (Singh and Goel, 2005). Despite products of powder metallurgy in automotive industry being generally made of iron powders for gears, paddle wheels and mounting rods, recently, usage of aluminium alloys has been gradually becoming widespread (Bishop et al., 2000). Significant process is necessary for development of some light alloys. AA 2014 aluminium alloys basically comprises copper, magnesium, manganese, silicon and other elements, and it is widely applied in the industry (Gavgali and Aksaka, 1998). Being the subject, molten metal's atomization mechanism in the process of production is incompatible in its production rate, speed and powder quality, besides its low consumption. Because of their high production rate and speed, close-coupled and free-fall nozzle systems are applied. Generally, while there is supplemented solidification with free fall inside atomization chamber, raw material is molten and atomization proceeds (Achelis and Uhlenwinkel, 2008). Production of metal powder through high pressure gas atomization technique plays a noteworthy part in powder

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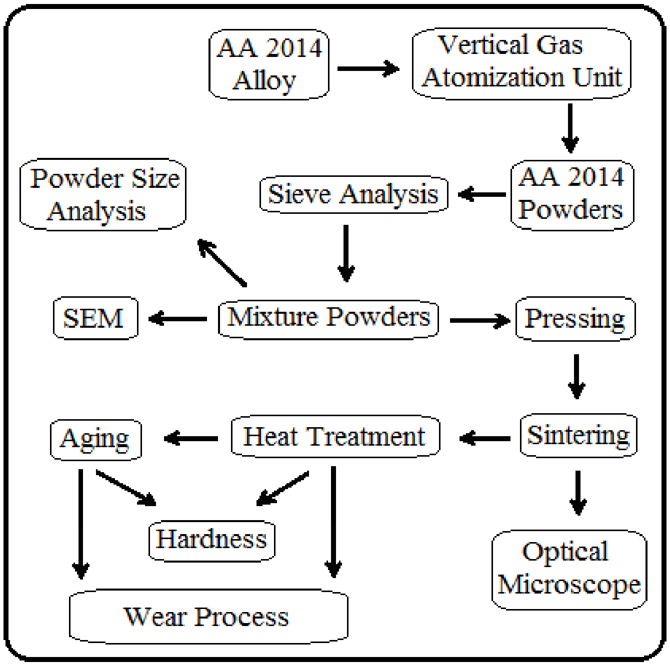


Figure 1. Flow diagram of experimental study.

Table 1. AA 2014 alaşımının kimyasal kompozisyonu (%).

Al	Cu	Si	Mn	Mg	Fe	Zn	Cr	Ti
93.5	4.06	0.6	0.57	0.56	0.47	0.106	0.03	0.01

metallurgy industry to produce spherical shape metal powders. Gain of smaller particle size and parameters' being controllable for high performance are significant in metal powder production industry (Tinga et al., 2005). Traditionaly, it was general belief that sintering aluminium powder products was hard and their features were weak. However, with fortification of some elements, pressing aluminium powder and enhancing the sintering process is achievable. Hence these alloys illustrate that the endurance and density, derived from pressing aluminium alloys and sintering, could be developed (Kent et al., 2005). The wear rate of Al alloys is high in air, whereas in vacuum platform it is low. Al alloys are used in corrosion platform and wear resistance of the ones containing Si is superlative to the others (Unlu et al., 2005; Bostan, 2008). Used widely in industrial applications, materials resistant to wear are to be light and effected less from environmental situations (Yilmaz and Kurt, 2005). The operating lives of machine parts can be promoted with the production of materials whose wear resistance is high. The analysis of machine damage shows that 75% of parts deformation is due to wear of friction surfaces'. In order for elongation of surfaces, the materials' resistance to wear needs to be increased. Under the circumstances where the wear stress is high and lubrication is not sufficient, a low coefficient of friction and wear resistant materials are chosen (Koksal, 2004).

For that purpose, by vertical gas atomization, AA 2014 powder metal alloy production has been realized. With pressing process under unidirectional pressure, powder metal alloy samples have been produced. After the sintering and heat treatments of powder metal samples under high purity of argon gas, the microstructural characterisation and their effects on the degree of hardness value have been researched. Finally, determination of powder metal alloys' wear characteristics is carried out.

EXPERIMENTAL METHODS

Powders of AA 2014 Aluminium alloys produced through Vertical Gas Atomization Technique were used in this study. Produced AA 2014 Aluminium alloy chemical composition is illustrated in Table 1.

In ascertaining average powder size of gas atomized powders, Malvern Mastersizer E part sizing instrument was utilized. Procedure phases during the study are presented also in the flow diagram of Figure 1.

Applying unidirectional pressing mould of 10 mm diameter in the pressing process, the mould and mould punch are made of hardened steel. Before pressing 1 g powder samples scaled with precision scales and got ready for pressing. Next, these pressed samples were used in sintering and further processes (Figure 2). Pre and post sintering density measurements samples of pressing were conducted through cubage and determination of mass with digital scales whose sensitivity was 0.1 mg.

In the processes of sintering and heating treatments of experiment samples, SFL (sc 1206 model) horizontal furnace was

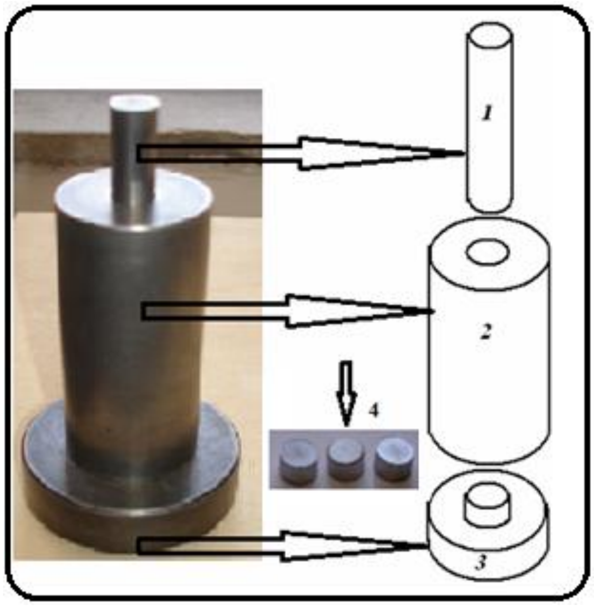


Figure 2. The solid model of pressing mold and experimental samples; 1. Moving punch, 2. Main body of mould, 3. Fixed base, 4. Samples.

applied. High purity Argon gas was used in the operations done with inert gas in the atmosphere controlled furnace. To enable increase in gas purity and to extract the moisture and oxygen, a second sealed tube containing copper chips was adjusted to 450°C' and connected to the system. In this way, oxidation behavior was decreased to minimum level by passing Argon gas through tube furnace. Sintering mechanism of pressed powder samples were experimented for 1 h at 550, 560, 570, 580, 590, 600, 610 and 620°C. For AA 2014 powder metal alloy's aging heat treatment, solution treatment at 520°C was applied and water-cooled. Later, these dissolution samples were subjected to aging process at 150°C for 4, 8, 12, 16, 20 and 24 h. By applying hardness test to the aged samples at every end of the aging time, the hardness results according to time were identified. In order for micro structural research and analysis of experimental samples, respectively, sanding, polishing and etching process were applied. Keller solution (1 ml HF, 1.5 ml HCl, 2.5 ml HNO_3, 95 ml H_2O)) as an etchant was used. Later, experiments were carried out with Lecia optical and scanning electron microscopes' (SEM) Joel JSM – 6060 LV model. In the hardness tests of samples, macro hardness measurements were conducted with INSTRON WOLPERT DIATESTOR 75551 Model device by using 0.500 g load. Post pressing and sintering of experiment samples, wear characteristics were examined through pin-on-disc wear device. 15 N load was applied to heated samples. Under this load, by calculating the samples friction and loss by weight at 400, 800 and 1200 m shear distances, the results were achieved. Imaging processes of wear surfaces were conducted beyond 1200 m. Wear losses of post heat treatment with aging process at 550ºC for 48 and 96 h and of heat treatment at 600ºC for 48, 144 and 196 h were turned into graphics.

RESULTS AND DISCUSSION

Confirming average powder size and size distribution graphics after analysis of AA 2014 powder metal alloys, average powder size was measured as 90.66 µm (Figure 3).

Examining the change of emerged powder shape's powder size, it was observed that in average size of 90.66 µm compound powders, small sized powders were spherical; whereas, relatively confirmed coarse grained powders were spherical, rod-shaped and close to spherical powders (Figure 4).

In the direction of pre trials of various pressing presures according to the conducted studies (Figure 5), optimum pressing pressure was chosen as 650 Mpa. Thus, when the gained density figures are scrutinized, increase in density at low pressure is fast at first; however, when the pores are closed, powder increasingly resists against condensation. Naturally, part hardness is a very crucial parameter for pressing (German, 2007).

To determine pore-structure interaction of sintering mechanism's operation and AA 2014 powder metal alloys for 1 h, eight different potential temperatures were tested. In Figure 6, micro structures of some were described. Taking this mechanism into account, it was stated that pores with increasing heat were irregularly shaped and plentiful, at the same time a negative effect in the point of material density. In Figure 7, similarly, it was illustrated through SEM image.

On the other hand, certain samples were heated to about 550°C for different time range, thereafter increase in heat process time and density rate were ascertained (Table 2). This density rise begins fixation after 12 h heat treatment. Through powder metallurgy, full dense part production is possible with secondary treatments or liquid

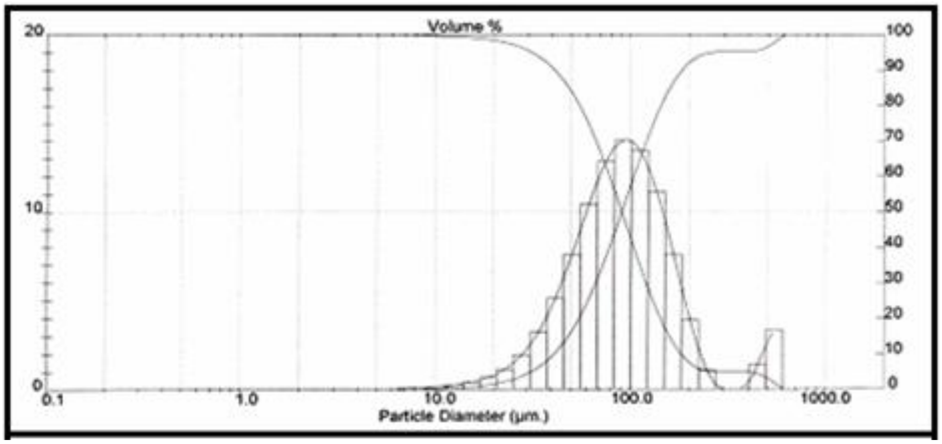


Figure 3. Particle size distribution of AA2014 gas atomized powder.

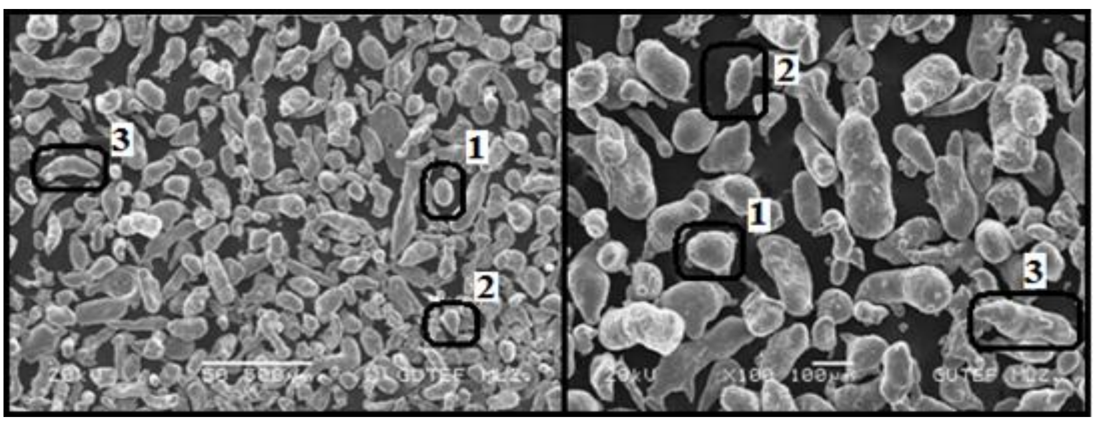


Figure 4. SEM images of gas atomization powders that avarage powder size 90.66 µm; 1. Spherical 2. Tear drop 3. Ligament.

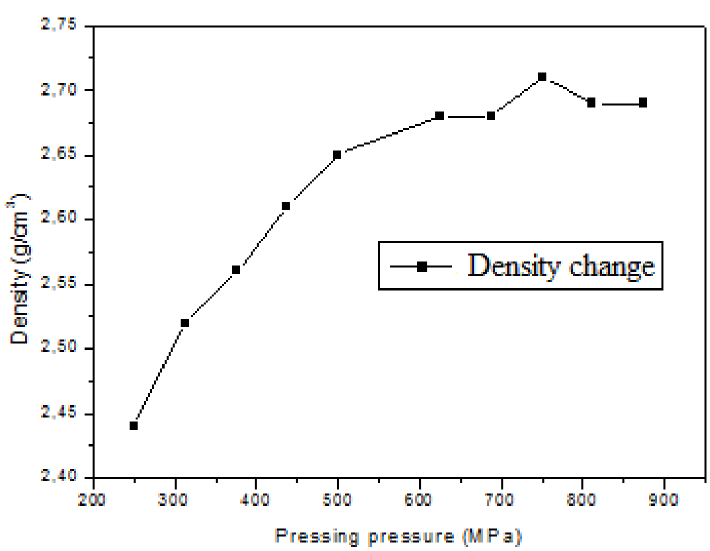
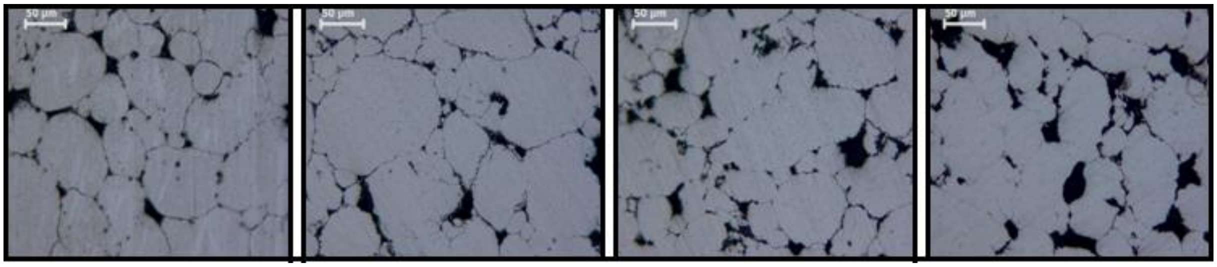
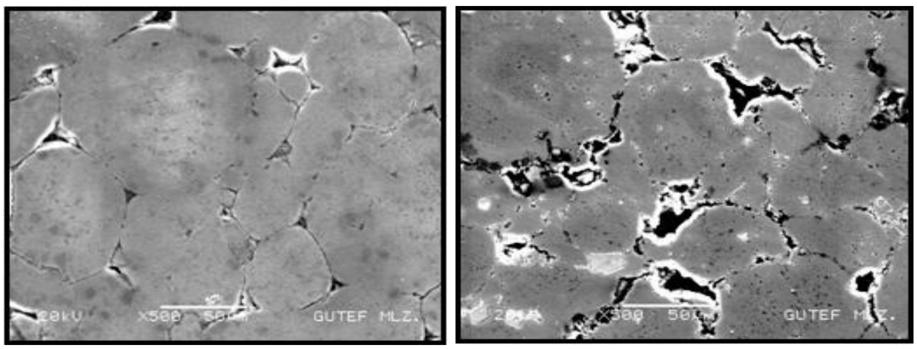


Figure 5. Density changes of samples in different pressing pressures.



550ºC – 1 h 580ºC – 1 h 600ºC – 1 h 620ºC – 1 h

Figure 6. Optical microscope images of samples sintering for 1 h at different potential temperatures.



550ºC – 1 h 620ºC – 1 h

Figure 7. SEM images of samples sintering for 1 h at 550 and 620°C.

Table 2. Density values for AA 2014 powder metal alloy

Sample no.	Heat treatment (Temperature, °C)	Heat treatment (Time, h)	Density as heat (Treatment, g/cm^3)
1		2	2.62
2		4	2.62
3	550	8	2.66
4		12	2.7
5		24	2.69

phase sintering. Taking cognizance of density of AA2014 material used in this context is about 2.75 g/cm^3, it is observed that density rises about 98%. This is a very high rate for density without secondary treatments.

Effects of increased heat treatment time and hardness depending on aging heat treatment in AA 2014 were determined. Scrutinizing Figure 8, an increase in hardness rate depending on risen heat treatment is observed. The probable cause in this increase in hardness rate is thought to be both macro and micro pores in structures with sintering and heat treatment inclining to grain boundaries and grains' forming new grains by combining.

Besides, effort was made to confirm aging heat treatment's effect on AA 2014 alloy's hardness rate. Hence, samples that received heat treatment for 4, 8, 12 and 24 h were subjected to aging treatment and gained curves were gathered as graphic. After 24-h heat treatment, highest hardness rate was acquired. In addition, it is observed that time remaining at the highest hardness rate is superlative to the other heat treatment times. With rise in heat treatment time, increase in hardness according to the aging time was confirmed to be adjuvantly effected. Approximately 70% of increase was observed, in contrast to without-aging process which revealed gained hardness rate to the determined hardness rate of post aging process (Figure 9).

In Figure 10, loss of wear according to the wear–share distances of the samples, first heated at 550°C for 48 h then aged for 16 h and first heated at 550°C for 96 h then

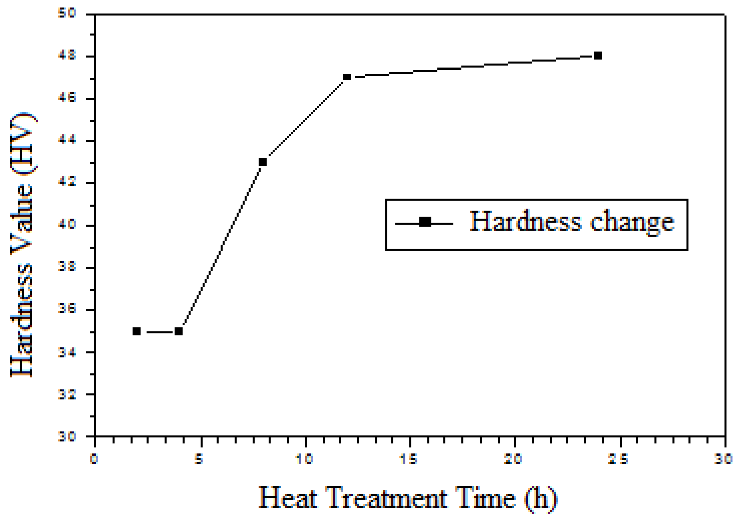


Figure 8. Hardness values at different heat treatment times.

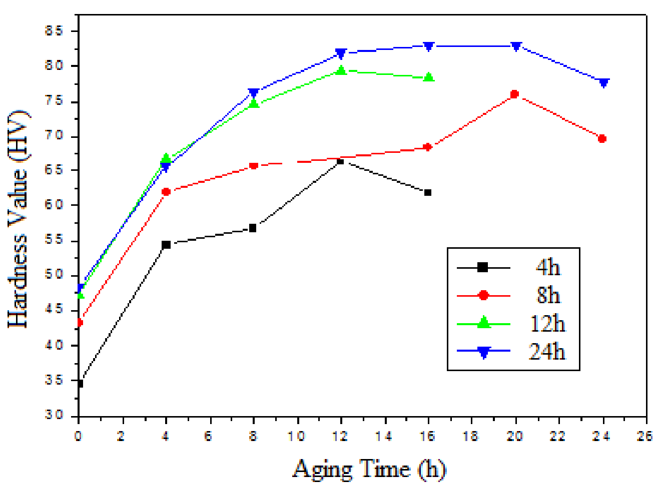


Figure 9. Hardness values of samples aged after heat treatment at 550°C for 4, 8, 12 and 24 h.

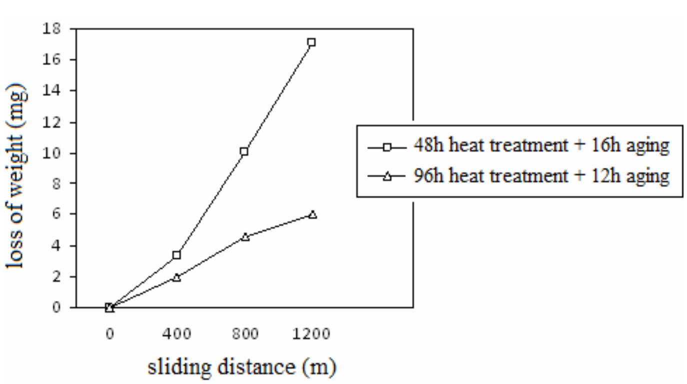


Figure 10. Loss of wear according to the wear-share distances of the samples heated at 550°C for 48 and 96 h then aged for 12 and 16 h.

aged for 12 h, were illustrated. It was observed that whole wear distance of wear loss of samples first heated at 550°C for 48 h then aged for 16 h samples was superior to that first heated at 550°C for 96 h then aged for 12 h. This result reveals rather than aging time, heat treatment time is much more efficient for wear characteristics. When these samples are scrutinized in Fıgure 11, it is obvious that mass loss of samples first heated at 550°C for 48 h then aged for 16 h samples is a lot more. In this sample, wear loss occurs as fracturing mostly because of adhesive mechanism (Figure 11a). On the other hand, on the wear surface of samples first heated at 550°C for 96 h then aged for 12 h, less wear tracks are detected (Figure 11b), wear tracks on this sample distinguishes itself mostly as ductile smearing and hence no much massive loss.

In Figure 12, wear loss of wear-shear distance heated at 600°C for 48, 144, 192 h samples were described. It can be detected that as regards the first 400 m wear-shear distance, the wear loss of these samples is less with increase in heat treatment time. The probable cause of this might point to rise in samples condensation with increasing heat treatment time and consequently rise in hardness.

The least wear rate after 400 m shear is observed for samples that received heat treatment for 144 h. However, before 400 m shear distance it occurs with samples that received heat treatment for longer duration. The probable causes of emerging less wear loss at this sample may be pointed out as either oxidation (Al_2O_3 film) over the surface of the sample because of the dry friction or local increase in hardness as a result of plastic deformation under wear weight of some ductile and YMK structured matereials such as Al alloys.

In Figure 13, after 1200 m shear distance, wear surfaces of the samples that received heat treatment at

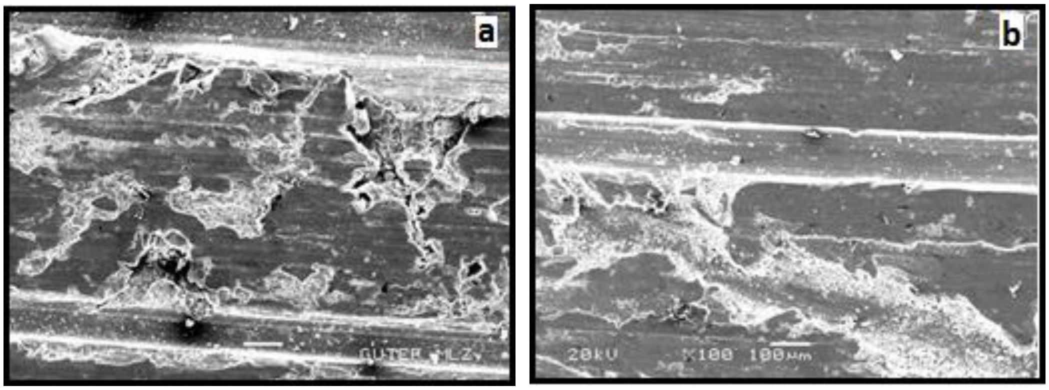


Figure 11. Wear surface of the samples heated at 550°C for 48 and 96 h then aged a) 16 h aging b) 12 h aging.

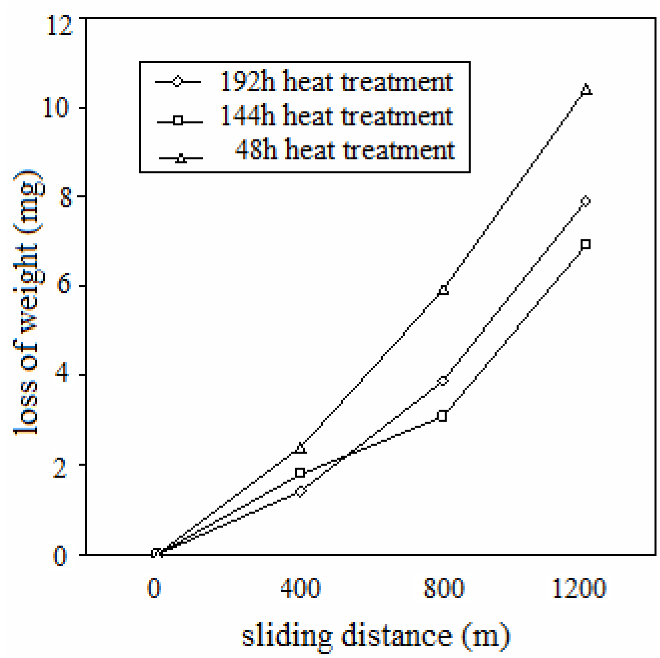


Figure 12. Loss of wear according to the wear-share distances of the samples heated at 600°C for 48, 144 and 196 h.

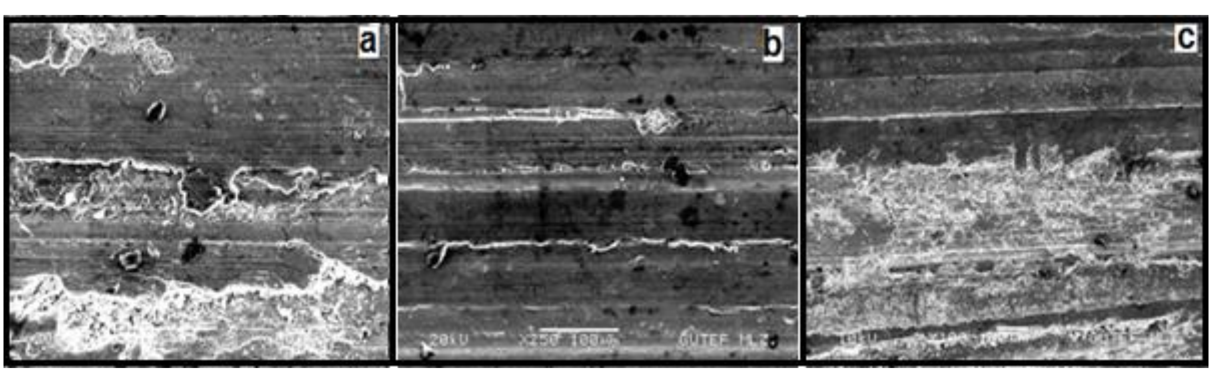


Figure 13. Wear surface of the samples heated at 600°C for different times; a) 48 h, b) 144 h, c) 192 h.

600°C for 48, 144, 192 h is illustrated. Examining the surface of the sample heated for 48 h, it is obviously seen that their mass loss is a lot more through deep wear tracks. Mass loss' being the result of adhesive wear mechanism is inferred from the ductile tears on the wear tracks of the sample.

Scrutinizing wear surface of the samples heated for 144 h, mass losses of them being far less is understood. It is observed that wear tracks on wear surfaces are not very deep or straighter. Additionally, being held by open pores to surface might trigger having less wear loss of fractured tiny parts of open pores to surface in the materials produced especially through powder metallurgy.

When wear surface of the sample is heated for 192 h, it is confirmed that wear is a lot more than wear surface of the sample that received heat treatment for 144 h, less than wear surface of the sample heated for 48 h.

Conclusion

The effects of pressing pressure, sintering and aging heat treatment, on hardness value and dry wear behaviour of AA 2014 powder metal alloy were investigated. The following conclusions can be drawn from the results of this study:

1) Average powder size of AA 2014 powder metal alloy produced through vertical gas atomization technique was determined as 90.66 µm and powder shapes (spherical, rod-shaped and close to spherical) likely to occur were observed.
2) Pressing pressure in the pre and post sintering process was thought to be important and optimum pressing pressure was identified as 650 MPa. Sintering temperature and time was determined to influence directly on porosity in the structure.
3) A significant increase was confirmed in hardness values with increase of heat treatment time of samples produced at 550°C. Approximately 70% of increase in hardness value in samples with aging process was observed.
4) Wear loss depending on wear-shear distance of samples heated at 600°C for 48, 144 and 192 h were detected, such that the first 400 m shear distance is less with increase in heat treatment time. The least wear loss over 400 m at these samples is shown to be with the samples that received heat treatment for 144 h.
5) Oxide occurence depending on heat increase generally appeared in wear experiments of samples, and was identified to affect wear loss. Similarly, the likelihood that wear loss will occur depending on increasing wear distances did not exhibit a linear rise as the distance was increased.
6) Increasing the heat treatment temperature and time is a result known to effect the amount of pore of powder samples. Porosities occurence depending on the distance in wear were observed to have an effect as if there had been a decrease in the amount of wear by keeping the wear particles.

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