www.rsya.org

Journal of Analytical Research

Vol 3 – Issue 1, Jan-Jun 2023

www.rsya.org/jar

Fabricate Specimens of Forged Aluminum by Unconventional Die

CHUNG SEON-U, NAMGUNG LEE*

Konkuk University, Neungdong-ro, Gwangjin-gu, Seoul, South Korea

*Corresponding Author: namgungkqu@yhaoo.com

Abstract. In many regions of the globe, a novel production technology is the forging of sintered metal-powder preforms. The sintered forging process is a cost-effective way to make metal powder pieces. For this study, instead of using tool steel to make an effective die, the authors used a modified die that was heat-treated to the proper temperature. Quenching is also used to harden the die material in specified areas. After sintering, the pores in the aluminium powder samples were found to be eliminated, according to various metrics and microstructure.

Keywords: Aluminum, Sintering, Powder metallurgy, Forging, Microstructure

1. Introduction

Today's world strives to increase its output rate through improving industrial processes, and the rise of automation is playing an important role in doing so. In addition to new technology, additional criteria must be examined in order to eliminate different harsh environment, to reduce time and energy consumption, and to efficiently use waste. This is the pinnacle of job excellence. Reducing energy consumption is more important than any other aspect because energy production generates enormous amounts of garbage (millions of tonnes annually), which is the cause of the extinction of several species and the death of tens of thousands of people. of people every year. As a result, energy conservation should be the primary goal. The contemporary working environment necessitates additional modifications to manufacturing processes to accommodate the need for high-performance materials that are both lightweight and strong. Low-weight components and goods may be made from aluminium, which is a kind of metal. Depending on kind and design of the item to be created, several manufacturing processes are used to produce aluminium parts. Some of the most common production processes for aluminium parts are castings and forged components. Even though it is not a standard forging process, we will talk about powder metallurgy and the sintering process [17] in the current study. It's also important to point out that the die used in the procedure isn't the standard H12 or H13 tool steel die, but a distinct metal composition. As a result, significant resources like energy and money may be saved and put to better use elsewhere. When compared to a typical production method, sintered forging has a number of advantages (see Table 1).

2. Literature review

Powder-forged products have both technical and economic advantages, and the process' importance has been highlighted in numerous ways, such as greater material usage than traditional forging, the removal of stages, and the ability to achieve tight weight tolerance [7]. In addition, he compares traditional and powder forging processes and finds following points: Three or more typical forging phases may be replaced by a single forging blow. It's possible to have a very nice surface polish. Because flash isn't needed, less material is needed. A significant amount of machining may be avoided. Typically, a powder weight of 1 percent may be monitored and lowered by 1/4 when particular precautions are taken. Pt/Al2O3 catalyst was examined by transmission electron microscopy under oxidizing conditions for platinum particle sintering and discovered that fast sintering may be done by heating specimen in air at 700 °C and after 8 hours the mean particle diameter rises from 50 to 300 [2].] He came to the conclusion that fast-growing particles have twin boundaries, and that these boundaries are linked to reentrant surface characteristics. He concluded that. The platinum particles became larger than the alumina pores (>1500) after 8 hours of heating at 700 °C. Compacting pressure, Sintering temperature, and powder particle size all had an influence on relative density while cold forging sintered powder preforms, as did other technical components of the process. The free surface was discovered to have cracks forming. Forging of metal powder and wrought material have distinct deformation patterns when compared, as may be seen by comparing the two processes. Both the metal powder preform's fracture mechanism and deformation parameters have been studied under axis symmetric compression. Fine powder results in an increase in forging ability and densification. For unlubricated specimens, barreling is more pronounced, whereas lubricated specimens exhibit greater surface movement [14]. Aluminum nanoparticles are studied for their ability to solidify using Molecular Dynamics simulations [11]. The effects of temperature, particle size, and crystallographic orientation on two and three particle sintering were examined. Sintering kinetics have been examined in relation to particle size. According to a quick review of the nanoparticle system, sintering in nanoparticles occurs at a pace of picoseconds. In the first stage of sintering, fast neck development is followed by slower densification.

In general, the shrinkage of particles and the neck radius are less impacted by particle orientation at a given temperature, but the crystallographic orientation has an effect on the neck radius at the same temperature. The introduction of closed die forging for net shape making [18]. Net shape forging using an enclosed die is covered in this article. It was observed that components manufactured with back pressure worked better than those made without back pressure in different studies, which were conducted in order to explore the possibilities of this die. Fe-2Ni powder for sintering in milled and as-received circumstances is examined for several parameters, including carbon content, particle size, sintering temperature, heating rate, etc. On further investigation, the slower heating rate was shown to increase final density [8] rather than liquid phase sintering. During the milling process, the silicon oxides are removed, resulting in a smaller particle size and a higher density. Various interfacial friction settings are tested to see how the deformation parameters of a sintered aluminium cylinder preform change during cold upsetting. For testing, several aspect ratios were used. The friction force between plate and sintered preform is a crucial factor during the upsetting process, assuming that a circular arc is formed following deformation from the bulged preform curvature. The findings of his studies lead him to the conclusion that for all aspect ratios, the growing value of real axial strain will lead to a rise in new axial strain in the upper part (barreled section) and lower part (truncated cone). The densification process moves more quickly when working with images with a smaller aspect ratio. As the specimen hits the plastic limit, it behaves in a similar way as a solid specimen. Using a single projected die, researchers examined the formability of an aluminium foam sandwich, and found that compressive stress had a significant effect on the sandwich's length, but a double projected die had no effect on it [15]. Under various strain rates, the bulging behaviour of porous aluminum-copper composites is examined [4]. Porous metallic compound was shown to be forging-capable when fractures appeared on the free surface at varied strain rates. It was analytically possible to derive the relationship between average forging pressure and composite height decrease. Forging ability in Al-Cu composite declines as strain rate and copper content rise, according to the results of the experiments. In aluminum-copper composites, brittleness and cracking are found at lower height reductions due to ductility up to 5% of copper. As copper percentage increases, the composite becomes more brittle and fragile. Wheels may now be made using a mixed aluminium forging method [16]. AlSi3Cr alloy wheels outperform traditional forged wheels in terms of strength, according to a study that examined the morphology of Fe-containing intermetallics when Cr was added to the Al-Si-Mg alloy. The topic of form heading under low-velocity dynamic forging is discussed using a circular specimen of aluminium powder [5]. Consider the upper limit technique, in which yield criteria and friction law choose the velocity field, to construct a mathematical model for the relative aver- age forging pressure at various strain rates. Parametric analysis reveals the relationship between forging pressure and the percentage drop in height over time.

Die loads and movement curves for a few specified ratios of relative densities are continually monitored throughout the process. For specimens with a strain rate of 1.5 mm/s and same relative density and the same die movement, there is a considerable rise in die loads of 20–30 percent. Sintered powder processing for a variety of engineering components has been invented [5]. According to prior research, the theoretical model's prediction of flow stress during low strain rate cold forging was in agreement with what was actually measured. After the deformation starts and before the plastic stage is reached, a high peak value strain is also recorded. The porosity of powder metallurgy components after sintering was investigated in terms of sintered aluminium composites during hot formation, and this provided insight into the formability of powder metallurgy components [9]. The parameters of strain hardening are derived from his research on workability and the failure zone. Die and powder metallurgy component design must take these two characteristics into consideration before pores develop as fractures on the free surface. Defect-free components are almost hard to make if this happens. Educations on the hot formability of various metal matrix compositions, such as Al-4WC, Al-4Fe3C, Al-4TiC, and Al-4Mo2C, have also been conducted, and the following points have been found. Mo2C is the most dense material in WC-reinforced aluminium composite, followed by Fe3C and TiC, with larger aspect ratios having a lower density than smaller aspect ratios. An associated hydrostatic tension causes the densification. Instantaneous stress and strain hardening exponent are used to demonstrate the safe zone for employees while producing forming limit diagrams. Critical densities for Al-4WC, Al-4Mo2C 89.2% 89.8% Al-4Fe3C 90% and Al-4TiC 93.50% are all different alloys. Tests are performed on steel alloy densities ranging from low to high to assess porosity, component microstructure, and phase fraction [1]. They examined fracture propagation in a Ni-rich area and concluded that fatigue crack behaviour is influenced by the microstructure's heterogeneity.

Table 1: Material comparison of conventional manufacturing process and sintered forging process.

	Conventional manufacturing process	**Sintered forging**
Used weight (g)	560	325
Finished part weight (g)	300	312
Material loss (g)	260	16
Material utilization	54%	95%

3. Die set design

In the die cavity, metal powder distorts with the application of strong compressive stress. An important consideration is the material used to manufacture a die, and the die material should match the material that is to be forged using the die in question. This is a critical consideration. In die-making, H12 and H13 tool steel are often utilized, however the high stock costs and high machining costs of these materials make them uneconomical. Steel 304 and mild steel are used in different parts of a modified die design to replace H12 or H13 (tool steel grade), depending on the needs of different sections. The following components make up the whole die set:

- Blanker (Mild steel)
- Bottom Support (Mild Steel)
- Punch (Mild Steel)
- Outer Section (Steel 304)
- Middle Section (Mild Steel)
- Inner Section (Steel 304)

Fig. 1. Die set.

Parts of the Die Set are seen in Figure 1. Aluminum powder is easily forged when high pressure is applied to a forging die that has an inner portion made of mild steel and polished with various grits of fine sand paper to produce a superior surface quality. The plunger and the die's central part are heated after completing the surface. Due to the need to improve the hardness and strength of the following items, care must be taken while selecting the heat treatment technique Fig. 2 depicts the procedure for oil quenching mild steel specimens. As previously mentioned, these components' hardness and tensile strength skyrocket during the Quenching process. Quenching may be done in two ways: with water or oil. Oil quenching is the preferred method due to its superior material qualities [10].

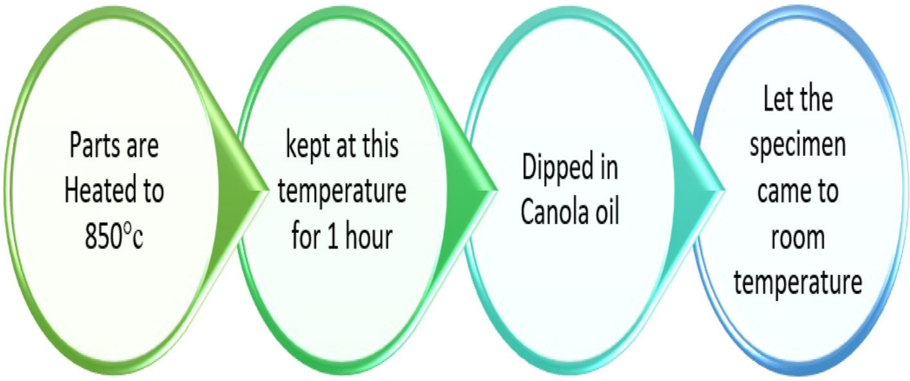

Fig. 2. Oil quenching flow chart

Specific components are heated in a microprocessor-controlled muffle furnace equipped with a digital metre that regulates and displays the temperature. After obtaining the desired 850°C temperature, Die-Set components are maintained in the furnace for an extra hour in order to achieve the recrystallization temperature. A quenching step is then performed by removing the components from the furnace and soaking them in oil (Canola Oil). If a high-temperature specimen is partially or incompletely immersed in oil prior to quenching, it might result in uneven cooling and loss of homogeneity. The failure of a component under high load might be caused by material distress resulting in poor homogeneity. An oil sample is taken out of its oil bath after its temperature has dropped significantly and is at a level equal to or lower than that of the sample material.

4. Fabrication process

Machines and equipment are needed in order to undertake a forging operation using this die. Making aluminium powder specimens requires the use of various machinery and equipment. One of the most often used machines for compressing aluminium powder is a universal tensile machine. In order to create solid aluminium specimens, samples are compressed in a Muffle Furnace before being sintered. This machine is used to polish the surface of the sintered forged preform after grinding and surface finishing processes have been performed in order to get a microscopic image of the specimen. An optical microscope is used to provide a microscopic picture of the sinter forged aluminium preform. Acquiring Aluminum Powder (Fig. 3) from M/s Qualikem Fine Chemicals Pvt. Ltd. Delhi, India, is the initial stage in the manufacturing process. Table 2 and Table 3 illustrate the powder's chemical and physical properties, respectively. The load-sinking temperature and other parameters are determined based on the characteristics of Aluminum Powder. In the second phase, the die cavity is filled with aluminium powder for compression.

Table 2: Aluminium powder Chemical composition

Test	Specification	Result
Assay	Min. 99.7%	99.9%
Maximum limit of impurities:		
Mn	0.0023%	0.0021%
Mg	0.00160%	0.00158%
Cu	0.00159%	0.00150%
Fe	0.17%	0.16%
Si	0.1313%	0.1310%
Zn	0.0053%	0.0051%

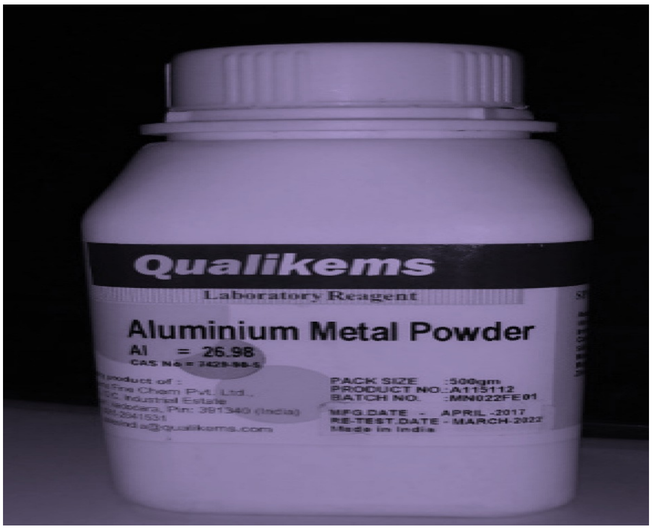

Fig. 3. Aluminium powder.

Filling the aluminium powder may be done by lowering the top section of the mould. The machine is halted and the load is removed when the preset load point is reached [13]. Step four involves gently ejecting the sample from the die cavity, which must be done carefully since the sample might break during this procedure. Fig. 4 depicts the die set configuration during the ejection operation as a schematic diagram. A banker serves as the new bottom support. Rather of delivering a quick and jerky load, the plunger must give progressive force and it is sent to a muffle furnace for sintering.

The cylindrical form of the die chamber results in the specimen's coin-like profile. Because the aluminium powder particles do not cling effectively to one another, the specimen is a bit brittle. The specimen is made denser and more cohesive by the sintering process. In order to sinter aluminium powder preform into the die cavity, the inside wall of the die must be greased. For two hours, an aluminium sample is held at 500°C in a muffle furnace. After that, it's chilled for two hours in endothermic sand. Cooled to room temperature in an open environment.

5. Results and discussions

Several variables impact the density of aluminium powder preform before and after forging. It's a delicate balance between these things. The following are crucial considerations:

5.1 Average size of powder particle:

In the third phase, a universal tensile machine slowly applies compressive force on aluminium powder in the die cavity while maintaining the bottom platform immobile. The powder particle size has a significant impact on the material's deformation properties and forging capabilities. Al-Powder sintered at 500 °C and compacted at 100 KN Reduced grain size results in preform densification and enhanced forging ability. When the particle size is smaller, a lower flow rate is achieved.

5.2. Compaction pressure

The density of sintered powder preforms has been shown to rise when the compressive pressure is gradually increased. At increasing compressive pressures, the forge's performance increases. Basically, the goal of sintering is to make green compacts stronger. Aluminum powder preform density changes with sintering temperature and compacting pressure, as can be shown. The forging ability of aluminium powder will improve when the sintering temperature is raised.

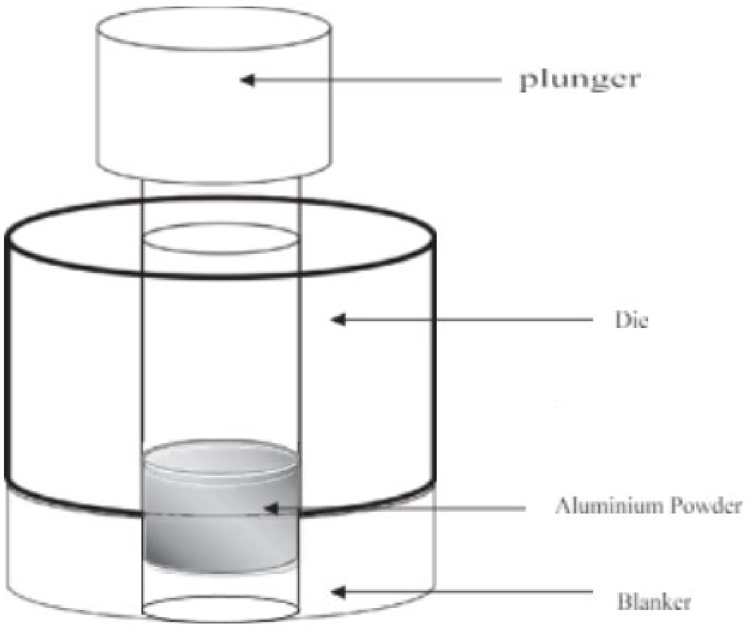

Fig. 4. Schematic diagram of die set

5.3. Experimentally and theoretically total work done

The experimentally acquired stress-strain curves are shown in Fig. 6. At 30 percent height reduction in the first two sets of tests, cracks may be detected on the equatorial surface. Therefore, 20 percent height reduction is set in the succeeding experiments, as well. Stress strain curves are plotted using MATLAB software, and a 20% decrease in plastic work is obtained. There is a very little difference between the two values in terms of relative importance.

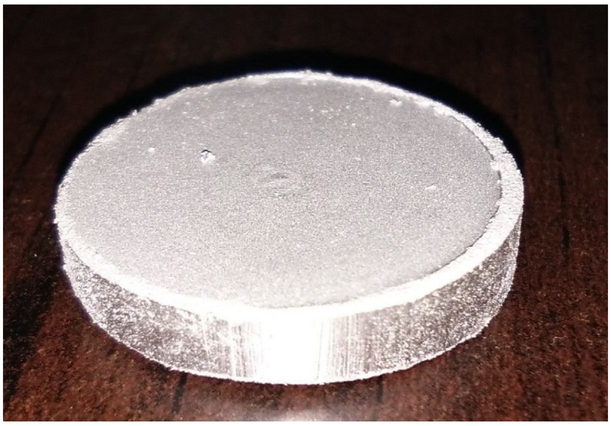

Fig. 5. Specimen of Forged aluminium powder

5.4. Impact of sintering on microstructure

The forged aluminium powder specimen's microstructure changes dramatically after sintering. A lack of full densification and the presence of holes on the specimen surface have been noticed after compacting the material with high loads. The pores on the surface of the specimens will disappear when the sintering process is completed.

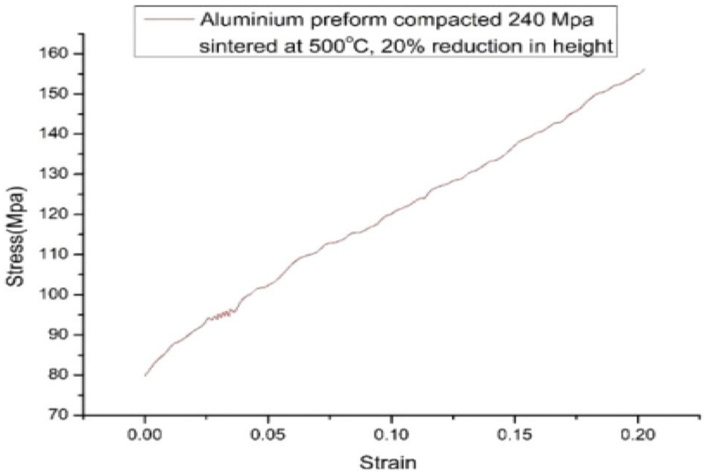

Fig. 6. sinter forged aluminium Stress strain curve

Sintering has an influence on density up to a certain point, according to this study. The qualities of the material will change and the product will behave in a different way if the specimen is heated any more. As can be observed, the pores have been eliminated from the specimen and the substance has become denser.

6. Conclusions

This work used sinter-forging to demonstrate the significance of strain rate during the mechanical processing of metallic composites. Strain rate has been demonstrated to influence open die sinter forging deformation at room temperature. The weight and volume of these samples are compared to determine their density. In light of the research's results and conclusions, it is clear that, In various sintered Forging techniques, the strain rate increases considerably as the die speed increases. Throughout the production process, powder particle size, compaction pressure, and sintering temperature all have a role in the densification of porous metallic specimens.

It is necessary to lower the grain size of the metallic powder and increase the compaction pressure and sintering temperature in order to improve the powder forging and densification capabilities. We may infer that the density of specimens varies with the applied force, and that the greater the applied stress, the higher the sample density will be. If the specimen is subjected to more stress, a fracture will eventually form Microscopic images of unsintered porous metal samples reveal porosity on their surfaces that are removed when the specimen is subjected to sintering, indicating that sintering plays a key role in densifying the sample.

References

1. G.B. Piotrowski, X. Deng, N. Chawla. (n.d.). Fatigue crack growth of sintered steels, in situ.
2. P.J. Harris, The sintering of platinum particles in an alumin-supported catalyst: further transmission electron microscopy studies, J. Catal. 97 (1985) 527–542.
3. S.K. Jain, R.K. Ranjan, S. Kumar, Deformation characteristics of sintered aluminum preform having different aspect ratio, Manuf. Technol. Res. 10 (1) (2014) 45–52.
4. S.K. Jain, R.K. Ranjan, S. Kumar, Polygonal porous aluminum-copper composite cold forging at different strain rates, Int. J. Mater. Sci. Manuf. Eng. 42 (1) (2015) 1166–1175.
5. S. Jain, R.K. Ranjan, S. Kumar, Cold forging of rivet shape head from cylindrical porous aluminum specimen at different strain rates, Int. J. Eng. Manage. Res. 5 (1) (2015) 209–216.
6. P.K. Jones, The technical and economic advantages of powder-forged products, Powder Metall. 13 (26) (1970) 114–129.
7. S. Jain, R.K. Ranjan, S. Kumar, Fracturing and deformation characteristics of aluminum preform during cold forging at low strain rates, Int. J. Sci. Eng. Technol. 186 (4) (2015) 1–6.
8. King, P. (2004), Presented at PM 2 Tec2004 Chicago, IL June 13–17, 2004.
9. S. Narayan, A. Rajeshkannan, Studies on formability of sintered aluminum composites during hot deformation using strain hardening parameters, J. Mater. Res. Technol., Braz. Metall. Mater. Min. Assoc. 6 (2) (2017) 101–107.
10. J.K. Odusote, T.K. Ajiboye, A.B. Rabiu, Evaluation of mechanical properties of medium carbon steel quenched in water and oil, J. Miner. Mater. Charact. Eng. 15 (2012).
11. J.S. Raut, R.B. Bhagat, K.A. Fichthorn, Sintering of aluminum nanoparticles: a molecular dynamics study, Nanostruct. Mater. 10 (5) (1998) 837–851.
12. Sharma, V.K. Dwivedi, Study of properties of sintered forged aluminum powder made by unconventional die, Int. J. Eng. Technol. Sci. Res. 5 (4) (2018) 737–742.
13. T. Sekiguchi, Forging of aluminum alloys, J. Jpn. Inst. Light Met. 44 (12) (1994) 741–758

14. Summary, Production of sinter-forged components, J. Mater. Process. Technol. 41 (1994) 143–169.

15. Takekoshi, Y. Kume, M. Kobashi, N. Kanetake, Deformation behavior in die forging of aluminum foam sandwich, Procedia Eng., Elsevier B.V. 81 (2014) 564–567.

16. M. Tocci, A. Pola, G.M. La Vecchia, M. Modigell, Characterization of a new aluminum alloy for the production of wheels by hybrid aluminum forging, Procedia Eng. 109 (2015) 303–311.

17. J.W. Wisker, P.K. Johns, The economics of powder forging relative to competing processes-present and future, Mod. Dev. Powder Metall. (1974).

18. H. Yoshimura, K. Tanaka, Precision forging of aluminum and steel, J. Mater. Process. Technol. 98 (2) (2000) 196–204