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Analysis Of Alumina Particles Size And Shape Formation From Developed Planetary Ball Mill

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ANALYSIS OF ALUMINA PARTICLES SIZE AND SHAPE FORMATION FROM DEVELOPED PLANETARY BALL MILL

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Abstract. This study emphasizes and the testing of alumina particles via a fabricated planetary ball mill. The fabrication of planetary ball mill work began with the design of the machine. Parts were fabricated separately then assembled. The jar and grinding media were made up of stainless steel as it as a higher strength property than Alumina powder. Testing and calibration are carried out through the response surface methodology utilizing the experimental results. Test is also executed to confirm the validity and the accuracy of the developed planetary ball mill. Based on the result obtain, the alumina powders have a particle size reduction of about 50% of the original particle size. Furthermore, the shape of the alumina particle changes from angular to irregular particle shape. It is apparent that the fabricated planetary ball mill able to grind the alumina powders and produce ultrafine particles by given period and parameter set. The fabricated ball mill able to function better than conventional ball mill. The planetary ball mill will be useful for the laboratory use purpose and production of ultrafine powder production. This ultrafine powder production can be used in application of powder metallurgy and advanced material research purposes.

1. Introduction

In recent years, powder metallurgy is widely used to produce relatively complex parts which have high strength, hardness and toughness properties. Powder metallurgy is a process where metals were powdered, compacted into desired complex shapes, and sintered to a solid bulk form. Powder Metallurgy is basically divided into three main processes; production of metal powders, compaction of metal powders and sintering [1,2]. In this research, it is concern specifically on the production of metal powders. Mechanical comminution is one of the methods to produce metal powders and the technique involves pulverization using a ball mill [3]. Ball milling is a process where metal powders placed in the ball mill is subjected to the collision from the grinding balls which is also placed in the ball mill machine. However, order to produce highest degree of fine metal powder, the Planetary ball mill is a most frequently used system for mechanical milling and alloying of powders because of strongly and violently movement of the ball, leading to large impact energy of balls that advances grinding and milling performance [4].

Subsequently, planetary ball mills are used for colloidal grinding, mechanical milling, and material development due to their good high impact energy, productive grinding process in short processing

times [5]. The planetary ball mill normally has 1 to 4 jars or normally known has vial. The vials are attached to a disk that been powered by motor that rotates around a central axis. And the pots were attached off axis that allow the vial to revolve around the disk and simultaneously rotating around their own axis [6,7]. The vial and the disk rotates at a high speed that leads to large impact energies of grinding media inside the vial to have a great grinding performance as shown in figure 1 [8].
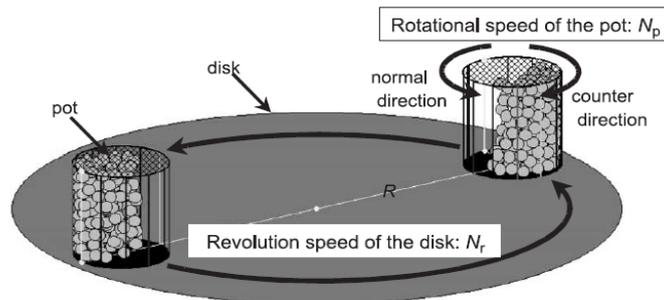
**Figure 1.** The Schematic configuration of the planetary ball mill.

Basically, when the powder is subjected to the ball mill process, its contents may be agitated and the action of the grinding has two effects. Firstly, the particles will be periodically break down, resulting in much smaller particles and secondly the shape of the particles is affected as the result of collision of the grinding ball and metal powder [7,9]. Therefore, high-energy planetary ball mill affects the particle size, shape and distribution of the metal powder. The concept of planetary ball mill as a high-energy mechanical milling process focus on the extremely high centrifugal forces produced from the rotating planetary ball mill gearing result in very high pulverization energy and therefore short grinding times [10,11]. The type of planetary ball mill used in industry is the Retsch Planetary Ball mill PM100 [12].

Furthermore, the principles of horizontal ball mill operations are limited regarding the fineness of the powder after milling. This is due to lack of the centrifugal field at the breakage zones. Low centrifugal field will cause weekly confined particle thus size reduction of particle powders is limited [10]. This low centrifugal field occurring in the vial is called cascading effect. This cascading effect is not as efficient have erosion effect. We need to produce a smooth erosion revolution to achieve the maximum impact energy for the ball to hit the powder and cause a particle breakage [13]. Alumina or also known as Aluminium oxide is a chemical mixture of aluminium and oxygen with the chemical formula Al_2O_3. Alumina have 2 majors used in industries: 90% of Alumina is smelted to produce Aluminium Metals [14,15] The use of alumina in this project is to analyse particle breakage.

Therefore, objective of the project is mainly to custom design and fabricate a low-cost planetary ball mill and analyse alumina powder's particle size, shape and distribution formation via custom designed and fabricated planetary ball mill.

2. Planetary ball mill Ball Mill Performances
The optimum impact energy can be achieved when the energy dissipation is reduced. Thus, the ball motion in the vial have to be in an erosion effect therefore the ball will detach from the wall and bombard a high intensity energy to the powders as shown in figure 2 [16,17].
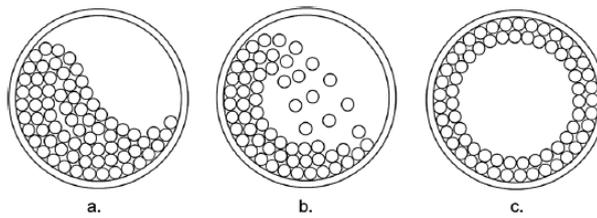
Figure 2. Scheme of a ball motion pattern in a single pot of a planetary ball mill –
(a) cascading, (b) erosion, (c) rolling.

Thus, neglecting the friction force between the ball and the wall of the vial and also the gravitational forces acting during the rotational of the vial, the impact energy can be calculated as follow :- planetary ball mill disk revolution and the vial rotation indicating by Wp and Wv whereby it is the absolute angular velocity of the disk of the planetary mill and of one vial and the Rp and Rv indicates the vectorial distances from the center of the mill disk to the center of the vial(jar) and also the radius of the jar as shown in figure 3 below [1,4] .
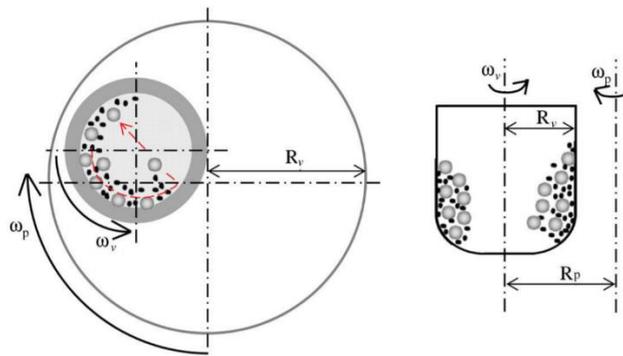
Figure 3. The schematic diagram of the planetary ball mill disk and the vial

2.1. Absolute Velocity

The Absolute velocity of one ball leaving the wall is given by:

$$V_b = [(W_p R_p)^2 + W_v^2 (R_v - d_b/2)^2 (1 - 2W_v/W_p)]^{1/2}$$

(1)

And subsequently the velocity of the ball in the vial with d_b diameter, after hitting the inner walls of the vials can be expressed as follow

2.2. Absolute velocity after hit

$$V_s = [(W_p R_p)^2 + W_v^2 (R_v - d_b/2)^2 + 2 W_p W_v R_p - (R_v - d_b/2)]^{1/2}$$

(2)

Next the Kinetic energy of the single ball is calculated using the mechanism of energy transfers.

2.3. Impact Energy of per ball

$$E = 1/2 \, m_b \, V_b^2$$

(3)

After a short succession of hits, during which decreasing fractions of kinetic energy are released, the balls residual energy becomes

2.4. Impact energy after hitting

$$E = 1 / 2 \; m_b \; V_s^2$$

(4)

and the total energy released by the ball during the refinement of the powders is given by:

2.5. Total Impact Energy per ball hitting

$$E = E_b \; - \; E_s$$

(5)

To conclude, mechanical grinding and comminution processes in planetary ball mills are complex and mainly dependent on the milled material or the desired product. There is no specific general rule for the choice of optimal conditions. Several parameters influence the success of each individual milling or comminution process therefore it is certain to make a good parameter assessment as it is discussed in the section above [5,17-18].

3. Design Methodology

This work planetary ball mill concept design based on vertical standing due to stability of the mounting. The vial is attached to the vial top and bottom cover for grip holding of the vial while rotational occur when the machine is on. The arm is attached to a flange and holds the planet gear align with the sun gear and fixed gear. The bearings are fixed at the planet gearing and at the arm for free rotational because it must not be influence by the sun gear. The motor, arm and fixed gear is mounted to the rig to support the whole system. The gearing designed have a fixed gear, a sun gear and two planet gears as shown in table 1. The gearing system was based on the module set for the gear teeth. As for this design, the module set was 2. The gear teeth as set to 2 because this process needed a finer rotational. Increasing the Module will make the rotational coarser and cause faster wear-ness. Thus, the pitch diameter was set for the sun gear was 80mm, Planet gear 40mm and fixed gear ,160mm. The thickness of all the gears was 10mm.Based on the pitch diameter and module set, the number of teeth for each gear can be calculated as shown in table 2 below.

A meshing of the prototype has been done using Autodesk Stimulation 2015 for the analysis of the displacement, von misses stress and safety factor of the concept design. The design was analyse and there was zero displacement occurred when the motor was set to rotational as shown in figure 4. Furthermore, the von misses stress has a maximum of 70MPa at the main shaft anyhow it has the lowest stress at the mounting rig as shown in figure 5. Next, the shaft at the rotating motor have a safety factor of 6 which is not so safe for the design. As shown in figure 6 below Overall view, the design is acceptable and is proceeded to the fabrication.

The 3 phase AC motor is used to generate power to rotate the sun gear. The power is 0.18kW. the voltage used for this motor is 480V therefore it requires a high voltage plug to fire up the motor. The motor generally has maximum of 1700 revolution per min. Thus, a speed control system is provided to control the revolution of the system. The specification of the motor as shown in table 1. The Assembly of the rig was done using MIG welding. Once the rig was fully weld, the components was fixed to the rig. The system weights approximately 10 kg. which is feasible and can be carried anywhere for grinding purpose. The Schematic dimension of the assemble and schematic experimental setup as shown in figure
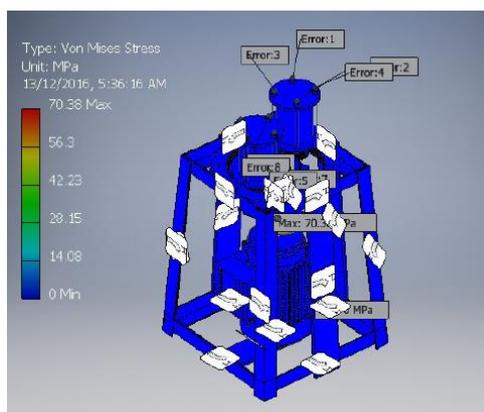
7, and 8 below. Table 3 and 4 is showing the parameters set for the calculation of impact energy of per ball hitting the powder and the vial.
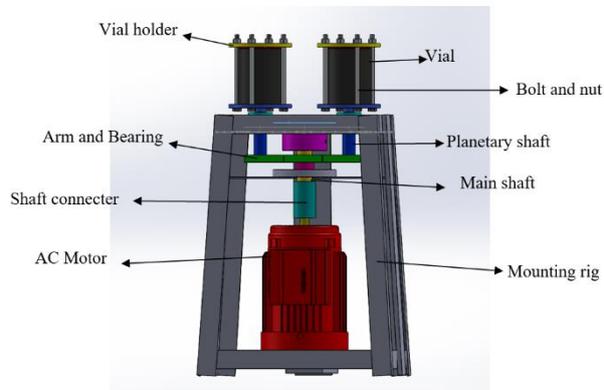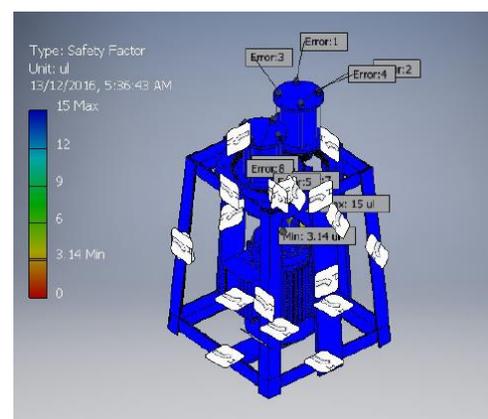

Figure 4. The design of the Planetary ball mill.
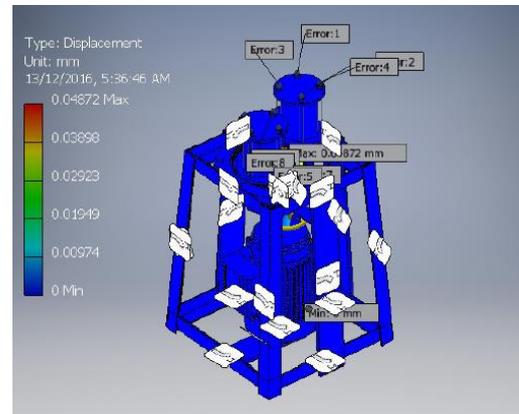
Figure 5. The displacement results

Figure 6. The Von Misses Stress Results

Figure 7. The Safety Factor results

Table 1. The technical specification of the design.

Specification	Values
Motor Spec	Three phase AC
Speed of the rotation Vial	50-400RPM
Centre of the vial to the centre disk	60mm
Vial	AISI 304 Stainless steel, diameter 60mm
Direction of rotating vial	Counter clockwise
Direction of AC motor	Anti-clockwise
Grinding Media	AISI 304 Stainless steel ball, 10mm and 6mm diameter
Weight of the ball	4.12g
Volume of the Vial	150ml

Table 2. Example of weightage setting

Spec/Type of gear	Planet Gear	Sun gear	Fixed gear		
Quantity	2	1	1		
Module	2	2	2		
Pitch diameter(mm)	40	80	160		
Number of teeth			20	40	80
Pressure Angle(º)	20	20	20		
Material	Carbon Steel	Carbon Steel	Carbon Steel		
Bore diameter(mm)	17	20	-		

Table 3. Technical specification of AC Motor

Specification	Values
Motor type	3 phase AC Motor Plug in
Revolution Speed	1400/1700 RPM
Horsepower	0.25HP
Power	0.18kW
Frequency	50Hz
Volts	415V

Table 4. Load for AC motor

| Wp	Wv	Rp	Rv	db(m)	mb(kg)
31.42	94.24	0.06	0.03	0.001	0.00412
15.71	47.12	0.06	0.03	0.0005	0.00412
31.42	94.24	0.06	0.03	0.001	0.00206
15.71	47012	0.06	0.03	0.001	0.00206

4. Results and Discussion

The void is filled with 25% of the ball as the grinding medium. The percentage of the ball being filled in the void is dependent to the number of ball and volume of the ball. Another 25% of the void is filled with the powder and again the powder filling is dependent to the volume of the powder [16]. Once the void is filled, the void is attached to the planetary ball mill. The planetary ball mill is then subjected to real time grinding. The machine with variable speed is controlled by using two essential RPM which is 150rpm and 300rpm. This speed was chosen to determine the influences of the differences in speed to the grinding of the alumina particles. Besides that, the ball size is also chosen based on the theoretical governing equation o the absolute velocity and impact energy produces during the grinding. The impact energy calculated was for per ball hitting the vial. Table 5 shows the parameters obtained for the theoretical equation calculated.

Based on the Parameters set, the calculation can be used firstly by the absolute velocity V_b of the ball travelling to hit the powder on the vial. Secondly, the Absolute Velocity Vs of the ball after hitting is

calculated. From this the Impact Energy of before and after is calculated by multiplying the ball's mass following the given diameter. The total Impact energy per ball is calculated by subtracting the both after and before impact. Thus, Table 5 shows the values after calculation. Figure 8 shows the bar chart of the impact energy.

Table 5. Impact energy of per ball hitting the alumina powders

| Absolute Velocity, V_b	Absolute Velocity, V_s	Impact Energy, E_b	Impact Energy, E_s	Total Energy Released, E	RPM and Ball Size
5.92287	4.66528	0.0722656	0.0448356	0.0274301	300RPM (10MM)
2.96144	2.33264	0.0180664	0.0112089	0.0068575	150RPM (10MM)
5.97813	4.68884	0.0368101	0.0226448	0.0141654	300RPM (5MM)
2.98906	2.34442	0.0092025	0.0056612	0.0035413	150RPM (5MM)
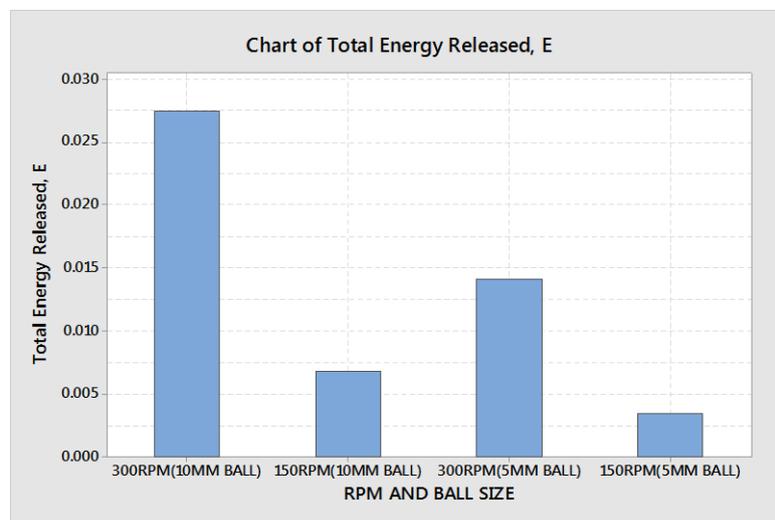
Figure 8. The Total Energy Released by each ball vs RPM and ball size.

Next, the planetary ball mill is tested with implementing the alumina powders into the vial and subjected to grinding. With the inverter fixed to the fabricated planetary ball mill, the grinding speed can be controlled. Therefore, the speed set for the grinding of the alumina powder is 150RPM and 300RPM. This speed of the vial is set to determine the influence of the speed to the particle breakage of alumina particles. This independency contrasts with powder fineness processes where ball diameter influences the alumina particle size. Following the ball size of the grinding chosen is 10mm stainless steel balls. And the grinding period set for each of the rpm was 3 hours, 5 hours, and 7 hours. The grinding hours was done for both 150RPM and 300RPM. Figure 9(a) shows the sizing of alumina particle against milling time for 300RPM. It is proven that as the grinding period increases the particle size of the alumina decreases. The particle breakage happened to the alumina powder is efficient by 50% decreased in size. Therefore, it is proven that grinding time influences the particle refinement of the grinding material provided there is a rotating disk and grinding media.

Figure 9(b) shows the sizing of alumina particle against milling time for 150RPM. The speed set is lesser than figure 9(a). However, it is proven that as the grinding period increases the particle size of the alumina decreases. The particle breakage happened to the alumina powder is efficient by about 20% decreased in size. Therefore, it is proven that grinding time influences the particle refinement of the grinding material provided there is a rotating disk and vial and grinding media. Based on results obtained

from figure 9, an interaction of both RPM had been made in figure 10 to see the differences in particle sizing versus the speed of the rotating vial in RPM. According to the graph, for 7 hours of grinding with 150RPM and 3 hours of grinding with 300RPM the particle size for 150RPM is only 7.10 micrometre while for 300 RPM it is about 5.60 micrometre which have produce much better result than the 7 hours of grinding with 150RPM.

The results also show that particle size reduce maximum which is about 3.30 micrometre at 300RPM and grinding hours of 7 hours in Figure 10. Thus, it is proven that higher speed of the rotating vial eventually speed up the refinement of the powder process. Lower speed does produce result but however low in efficiency than higher RPM. And from the results obtained above it is also proven that alumina powder can be refined more by allowing more hour on grinding so that powder is subjected in high speed impact energy grinding.

(a)   (b)
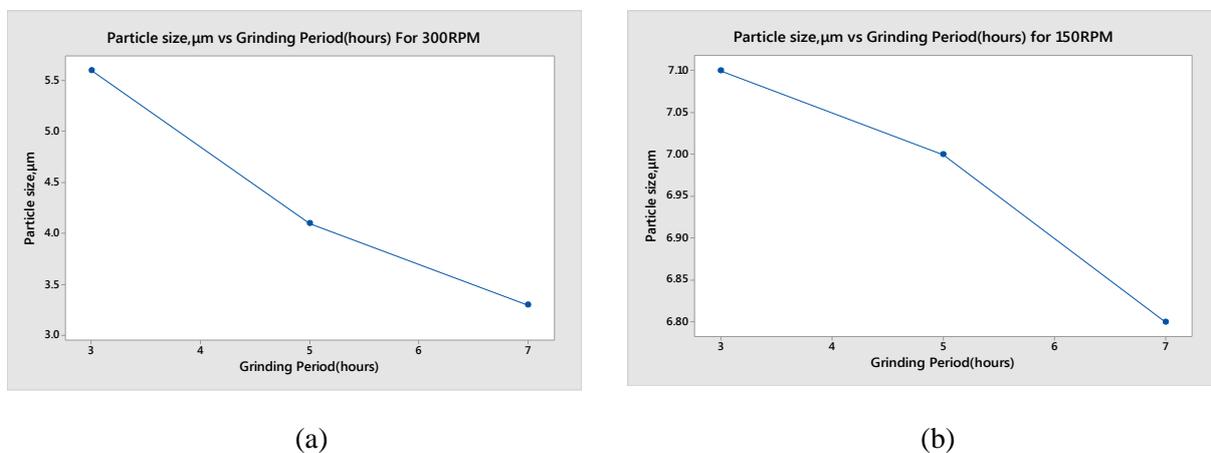
Figure 9. Scatter diagram of particle size vs grinding period (a) 300RPM and (b) 150RPM
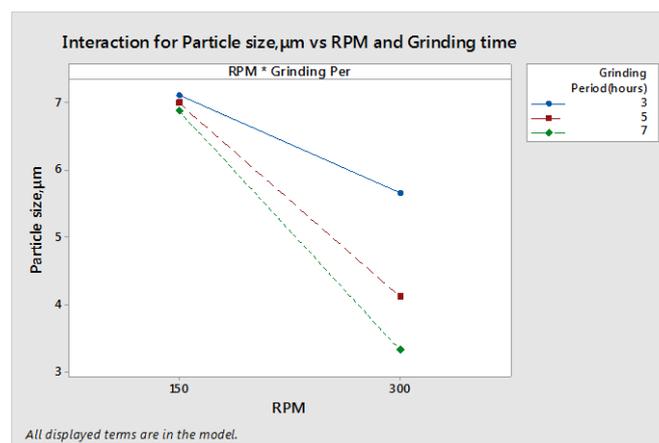
Figure 10. The interaction of particle size vs RPM and grinding time

5. Conclusion

The system works efficiently with minimal problem. In this design and development, analysing of particle size, shape, and distribution formation of grinded alumina powder with fabricated planetary ball mill. Many factors had been considered in fabricating the planetary ball mill. Primarily, the planetary gearing system itself. With two vials attached to the planetary gears, the epicyclic gearing of the

planetary ball mill had to be planned and designed properly. The number of teeth is calculated accurately to produce a speed ratio of 1:3. Design optimization takes place where it undergoes proper design and drawing of the entire system to ensure it is functioning well upon the real. The 3 phase AC motor is supportive enough to generate power supply for the rotational of the disk and vial. The vial and the grinding medium ball is made up of stainless steel enough to grind the alumina powders. While post grinding of the alumina powder concludes that there was refinement of alumina particles. Upon results and literature review, refinement and comminution of planetary ball mill are complex and mainly dependent on the speed of the rotating vial, sizing of the ball (grinding medium), and the time for the grinding or milling. An increase in speed of the vial will increase the performance of the planetary ball mill. The larger diameter of the ball produces more impact energy and better breakage of particles. And longer the time given for grinding, then more colloidal grinding occurs and finer product received.

As for recommendations, the device must be developed into single phase rather than three phase power supply to rotate the planetary ball mill. The 3 phase power supply needs 415V so it is restricted to be used in certain areas only such as mechanical laboratory. If a single-phase motor is use, it could be more convenient and reliable to use anywhere which have a 3-pin plug and would be much safer to. In addition, the gearing system of the planetary ball mill can be done in a gearbox concept to reduce the noise frequency where the ball mill can be monitored closely without any noise pollution.

Acknowledgement

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