COMBUSTION OF ALUMINIUM PARTICLES: A SHORT REVIEW

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ABSTRACT

Aluminium combustion is a key area of study. It plays a vital role in combustion processes, especially in propulsion systems. Its reactivity and explosive nature make it a sought-after material. This review summarizes research on aluminium combustion. It looks at what affects the combustion process. The study of aluminium combustion covers how it burns. This involves complex chemical reactions and physical processes. Studies show that the size of the aluminium particles and the amount of oxygen matter a lot. They influence how easily and quickly aluminium ignites. Smaller particles and more oxygen led to faster ignition and shorter burn times. Aluminium combustion is used in many industries. It is in rocket propellants for space, metallurgy, and materials that release energy. Thus, it helps in aerospace, automotive, defense, and materials science advancements.

INTRODUCTION

Aluminium (Al) is a lightweight and strong metal that doesn't rust easily. It is used in solid fuels, fireworks, and to make hydrogen. Its burning process is important and is widely studied. Adding tiny aluminium particles helps make hybrid rocket motors work better. However, Beryllium is not used even though it burns hot. This is because it creates very dangerous byproducts.

When boron burns, it creates a layer of boron oxide on its surface. This layer slows down its burning. Aluminium, on the other hand, is common, safe to use, has a lot of energy for its size, and burns very hot [84 kJ/cm^3]. Using very small aluminium particles in fuel helps it burn better and prevents the particles from sticking together. The smaller the particles, the quicker they catch fire, according to the d^2–t law.

Nano-sized aluminium particles are tiny. They burn faster and more easily than larger, micro-sized particles. They need a lower temperature, about 727°C, to ignite. This is because their protective layer breaks down quicker.

As the particles get bigger, they release energy more slowly. Heating them a lot can make them catch fire quicker.

These tiny particles make energy come out quickly and shorten the time it takes to start burning and to burn up. But their use in solid fuel is not widespread because of a tricky Al_2O_3 coating. This coating makes it harder to process the fuel and lowers its quality and power.

This review examines how Aluminium burns, its key factors, and its uses. We'll look into past research to see what affects its burning. We're also interested in how it affects industries and science. We'll pay close attention to particle size, temperature, and oxygen levels. We aim to examine what determines Aluminium's ignition temperature and burning duration.

A BRIEF HISTORY

Since the 1960s, researchers have explored how Al-particles burn. They discovered that aluminium particles do not vaporize at the common surface burning temperature. Instead, they temporarily stick to the surface they are burning on (Hashim 2018, 2). When exposed to air, aluminium forms a thin, inactive Al_2O_3 layer on its surface. This layer makes aluminium burn more slowly. Aluminium oxide, the material of this layer, melts at about 2077°C. This temperature is much higher than aluminium's melting point (Dilip Srinivas 2016, 2; Hashim 2018, 2). When the heat reaches about 660°C, the aluminium beneath starts melting. This causes the protective Al_2O_3 layer to crack under stress. Molten aluminium then leaks through these cracks, forming large clumps. At about 2047°C, the oxide layer completely melts and remains separate from the molten aluminium. As a result, the clumps shatter into smaller, Al_2O_3-coated droplets. These droplets rapidly oxidize, causing a swift rise in temperature (Hashim 2018, 2). The process of an Al particle burning is depicted in Figure 1.

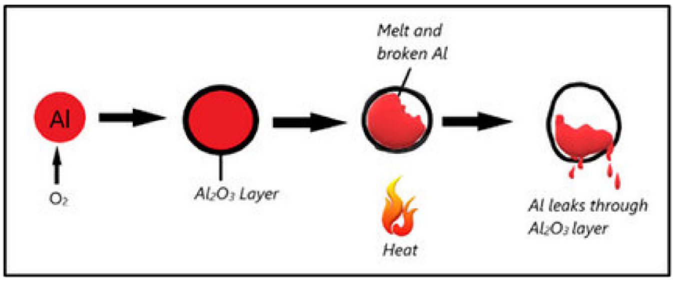

Fig. 1: Different phases of aluminium particle under heating.

ALUMINIUM COMBUSTION MECHANISM

Aluminium combustion happens through several vital mechanisms. When heated, Aluminium forms a protective layer of Aluminium oxide (Al_2O_3). This layer stops further oxidation of the metal beneath it. The central part of combustion is when Aluminium reacts with an oxidizer, like oxygen or halogens. This reaction is exothermic, meaning it releases heat, light, and various combustion products. The heat from the reaction helps light up nearby Aluminium particles, causing them to burn as well. The size of these particles affects how Aluminium burns. During combustion, gas-phase reactions occur between the combustion products and surrounding gases. These reactions create intermediate species and release more heat. Heat and mass must be transferred between particles for the combustion to spread. This process is crucial for the ignition and movement of the combustion front through a bed of particles. Aluminium combustion creates a very bright and hot flame. This flame's characteristics depend on the combustion temperature and the distribution of the particle sizes.

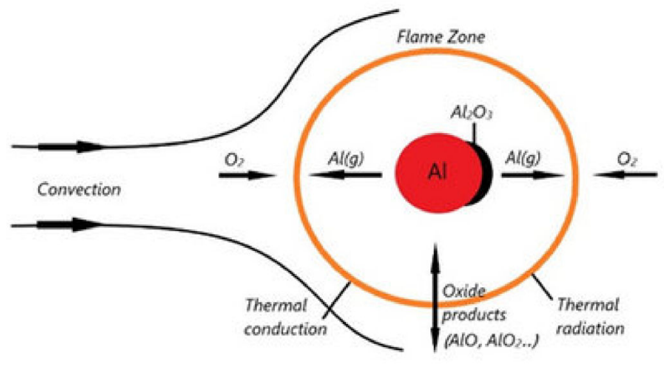

Fig. 2: Model of Aluminium combustion

Fig. 2 shows Aluminium particles catching fire. Some of the burnt product turns into vapor, while some condenses. The vaporized oxide can move to the surface or escape into the air. Adding more oxidizer or increasing the gas temperature makes the flame hotter. This heat can boil the oxide, turning more of it into vapor. This lets the material move away from the flame and alters the gas flow around it. Heating Aluminium particles makes them lighter. This happens as water evaporates and oxygen reacts with the surface, creating an oxide layer. But, if the oxide layer gets too thick, it stops oxygen from reaching the Aluminium.

This makes oxidation slower and can lead to the breaking of the oxide shell. This happens if the temperature goes beyond the melting point of Aluminium (Haidzar 2020, 3). TGA tests have been used by researchers to extensively study the reaction between Aluminium and oxygen.

FACTORS AFFECTING IGNITION TIME

Particle Size Effect

Studies find that particles more significant than 100 micrometers (μm) ignite close to Aluminium oxide's melting point. This temperature is around 2077°C. This happens because the oxide layer must melt from heat expansion before the particle can ignite. Particles sized 1-100 μm can ignite at temperatures ranging from 1027 to 2027°C. Nano-sized particles, however, ignite at much lower temperatures, like 627°C. This lower ignition temperature is due to a phase change in the oxide layer on the particle's surface. Nano-aluminium particles burn in three stages, while micro-aluminium particles burn in four stages. Scientists have done many experiments on how particle size affects burning. They found that the burning time increases with the square of the particle's diameter. When comparing the burning times of different particles, they confirmed that the 'd^2–t law' is accurate.

Effect of oxidizer concentration

Several studies have shown that the burning time decreases with higher oxidizer concentrations, as observed by researchers. Oxygen content significantly influences Aluminium combustion. Higher oxygen levels lead to quicker burning times and higher temperatures (Haidzar 2020, 6; Brooks 1995, 3).

The oxidizer type also matters. Oxygen affects the burning rate the most, while CO_2 affects it the least. This is because oxygen has twice the oxidizer content per mole than carbon dioxide. This could make combustion faster with oxygen than carbon dioxide (Brooks 1995, 4).

Effect of the temperature

The surrounding gas's temperature went up, which made the burning rate increase almost linearly. This continued until the flame's temperature neared the oxide's boiling point of about 1227°C. Then, the increase in burning rate became much steeper. Also, a rise in ambient temperature by around 27°C made particles 6.7 times more likely to ignite. This illustrates the significant impact of ambient temperature on combustion ease.

APPLICATIONS OF ALUMINIUM COMBUSTION

Aluminium combustion finds extensive applications in propellants across various industries, notably aerospace and defense. Aluminium is crucial in solid rocket propellants because it releases much energy when burned. In these rockets, Aluminium particles add to the fuel, boosting the propellant's energy. This leads to higher thrust for efficient space exploration, satellite launches, and military use. When Aluminium burns, it reacts with an oxidizer to create hot gases. This creates safer and more efficient propulsion than traditional rockets. Aluminium powder is also essential in pyrotechnics and explosives, increasing their energy and combustion rate. In the military, it is used in ammunition and incendiary devices for its quick combustion and high energy.

Aluminium is widely used in various fields, such as metallurgy, welding, and chemical synthesis. It is vital in heating industrial furnaces. It also plays a crucial role in thermite reactions. These reactions help in welding and cutting metals by burning Aluminium. Additionally, the combustion of Aluminium is helpful in applying thermal spray coatings. It also aids in chemical synthesis processes (Piercey 2010, 3).

CONCLUSIONS

The review paper examines the burning of Aluminium in detail. It discusses its mechanisms, influences, and industrial uses. The paper focuses on how particle size, oxygen concentration, and temperature affect Aluminium's ignition and burning duration. It finds that Aluminium with smaller particles ignites at lower temperatures and burns more quickly. The paper highlights oxygen's crucial role in burning, noting that increased oxygen levels result in hotter, faster burning. It explains that the spread of the gas mixture controls the burning speed. The paper also talks about how burning Aluminium is used. It is used in rocket propulsion and metal processing. It is also used in making fireworks and explosives. Other industries use it too.

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