Application 2070

Aluminum-Water Reaction for Hydrogen Production On-Demand

Shani Elitzur, Alon Gany, Valery Rosenband
Technion- Israel Institute of Technology, Haifa, Israel

Our research investigates hydrogen production and storage using the chemical reaction between aluminum and water, based on an original aluminum activation process developed and patented by Prof. Alon Gany and Dr. Valery Rosenband. The activation process involves a small fraction (typically 1-2.5%) of LiH activator and enables the reaction of aluminum with any type of water (tap water, sea water, and grey water) at room temperature to produce hydrogen at high efficiency (typically 90% and more). We further investigate the application in fuel cells, which enables high electric energy storage of up to 2200 Wh/kg Al. We demonstrated this technology with model electric boat and car powered by electricity generated by an on-board PEM fuel cell fed by hydrogen produced in-situ from the reaction of aluminum and water. http://youtu.be/MJDnBR5X08g.

This technology for on-demand hydrogen production and energy storage has various applications, including emergency generators, electricity supply in remote communication posts, unmanned aerial and underwater vehicles (UAV, UUV), electric cars, and auxiliary power units in commercial aircraft and trucks.

In all applications the technology enables green, safe, and compact electric energy storage. Safety aspects are important for further implementation of our technology, and safety experiments and characterization of the activated aluminum powder can greatly improve its potential to be a widely use source for hydrogen energy.

The material to be tested and characterized is an activated aluminum powder. Typical particle size is about 10 micrometer. The activation process comprises diffusion of LiH or its composing atoms into the aluminum lattice. The powder will be send to KIT. We are familiar with the delivery procedure.

Attached please find the Al powder safety data sheet.

We would like to conduct the following safety experiments with our activated aluminum powder, and receive among other results the dust explosion class of the powder:

1.Explosion indices
2.Lower explosion limit
3.Minimum ignition

We would also like to conduct those experiments with regular aluminum powder, for reference.

I would like to emphasize that such facility for safety characterization is not available at the Technion, nor it is available in Israel, to the best of our knowledge.

The experiments description follows:

One of the safety issues of any combustible powder is its explosibility. In case the powder is dispersed in air and being ignited, the powder cloud can explode generating severe pressure and/or heat loads. The explosion severity depends on many factors such as the specific heat, combustion /explosion rate, powder cloud geometry, initial temperature and pressure, etc. There are several standards to classify generally the explosibility of industrial powders and to determine the characteristic explosion parameters. Normally, these parameters are: pressure generated at adiabatic explosion, the rate of pressure rise, limiting explosion dust concentration (upper and lower), limiting oxygen concentration (needed to calculate necessary dilution of the industrial atmosphere to mitigate/avoid the dust explosion), and minimum ignition energy. As the powder explosion parameters evidently depend on the powder cloud concentration, the characteristic values are for the optimal concentration at which the explosion is most severe.

The industrial powders are normally divided in three classes distinguishing their explosive properties.

Aluminum powders belong to the severest St3 Class. The explosion behavior of Al powders is thoroughly studied. It is known that the fine Al powders can explode generating all spectrum of the explosion regimes including detonation even in atmospheric air. So the main interest of the new Al-based material is to compare its explosibility with the corresponding Al powder to clarify if the safety regulations elaborated for Al powders are suitable for the new material.

It is well-known that the explosion characteristics of powders strongly depend not only on the characteristic particle size but also on the form of the particle size distribution.

In this view it is necessary to use the same Al powder, of which the new material is made, as a reference material for comparative analysis of the explosion properties of the new powder.

One of the most frequently used method to measure the explosion properties of a powder is '20-l Siwek spherical bomb'. Its advantages are the method simplicity, need of small amounts of powder to test, low costs, huge database available on practically all industrial powders to precisely position the tested dust amongst the others. The method is to form a dust cloud in a standard combustion bomb, ignite the cloud at the sphere center, and record the pressure evolution during the explosion properties. Standardized are the sphere material and volume (steel, 20 l), wall temperature (20-25 C, water-cooled), initial pressure (1 bar), ignition energy (up to 1o kJ), and, of very high importance, powder dispersion process. The latter determines the initial turbulence level in the powder cloud, and its decay afterwards. The turbulence has a great impact on the severity of powder explosion, so to keep the same turbulence is very important to get standard results.

The measurement installation consists of 20-l steel sphere with water jacket, connected to a vacuum pump, dust storage container of 0.6 l volume, where the tested powder is loaded, a dust outlet valve connecting the dust container and the sphere, and igniter electrodes fixing an igniter at the sphere centre (see the picture). Before the test, some amount of tested powder is loaded in the container which is then closed and pressurized with air to 21 bar abs. The sphere is evacuated to 0.4 bar. At the test start the dust outlet valve is activated to open and let the dust with a portion of compressed air to be injected into the chamber. The dust comes inside and dispersed homogeneously in the sphere.

After the dispersion process is completed (all the air from the container gets inside the sphere), the pressure in the sphere is 1 bar.

At this moment the dust outlet valve is closed detaching the container. After that the igniter (normally, coupled of two pyrotechnical ones), placed at the sphere center, is activated and igniting the cloud. The pressure evolution is measured by high-speed pressure sensors.

All the explosion parameters are results of pressure-time curve analysis.

Normally a dust is tested in several series. Explosion pressure and pressure rise rate are measured in three identical series to average the stochastic spread of the results. Each series consists of a number of tests differing in dust concentration. The series starts with a suppositional minimum explosion dust concentration and proceeds with multiplied concentration to get the maximum explosion pressure and/or pressure rise rate. After that some more dust concentrations are tested to assure the maximum values are over. Then comes the lower explosive concentration measurement. It is also performed in three identical series. Each series starts with the concentration slightly above the one at which about 1.5 bar explosion pressure has been measured, and proceeds with stepwise decrease in dust concentration. The step value depends on the required accuracy of the measurements.

The last test series is to evaluate the minimum ignition energy. Standard igniter has 10 kJ heat release. The measurements start with this igniter, and proceed with successively reduced ignition energy. As the igniters are also standard, available are the ones of 10, 5, 2.5, 1, 0.5, 0.25, and 0.1 kJ. Aluminum is highly reactive material, sol it could be ignited even by the weakest pyrotechnical igniter. If it is the case, the test series will continue with a weak electric spark igniter.
The number of tests necessary for the project is as follows. Each series to measure explosion pressure and pressure rise rate will consist of 8-10 tests. The series to measure lower explosible limit requires normally 5 tests. Ignition energy measurements include 5-10 tests. Taking into account the triplication, one results in 75 valid tests. The same number is for the reference tests with origin Al powder.

Usually one test takes about 40 min. So the maximum number of tests a day is 10.

The whole test run should take 20 days: 15 days for valid testing and 5 days reserve.

Necessary amount of powder.

It is known that optimum dust concentration of Al powder of 10 µm particle size is about 800 g/m3. So the explosion pressure test series would consist of the tests with 50, 100, 200, 400, 600, 800, 1000, and 1400 g/m3 powder concentrations. In our case of 20-l volume, it means about 100 g of powder. Lower explosion concentration of the tested powder can be estimated as 100 g/m3. For 5 tests it requires 10 g of powder. Minimum ignition energy tests must be performed at optimum dust concentration, supposedly 800 g/m3 in our tests. For 10 tests it gives 160 g of powder. Altogether is about 800 g of powder for valid tests. The same is the amount of the origin Al powder.

Materials and spare parts.

- Cleaning materials. The measurement accuracy depends drastically on how accurate the chamber and the outlet valve are cleaned of the burned dust rest. It requires a lot of efforts and materials, too. The materials are ethanol, rags, glass-paper, dust filters for vacuum cleaner.
- Gases. Compressed air is used to pressurize the dust outlet valve, and to clean the installation.

- Safety measures: masks, gloves, work clothes.

- Seals and gaskets for the sphere, dust outlet valve, vacuum pump. The combustion product of Al powder is Al_2O_3, highly abrasive stuff. It wears the seals very quickly.

- Moving parts of the dust outlet valve. Al powders can produce very high pressure rise rates. Such explosions damage the moving parts of the valve very quickly.