

FEATURES OF ALUMINUM HYDRIDE COMBUSTION

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Introduction

Conditions and parameters of disperse aluminum hydride (AH) combustion in the form of air suspension differ from those of other well-known chemical substances substantially. It mainly concerns abnormal low limiting conditions of ignition and combustion of AH and also the parameters and consequences of explosion of AH particles air suspension.

The aim of this research was to investigate the features of the combustion of disperse AH in the layer and in the air suspension.

The surface of the sample particles tested during the research was treated in a certain way to reach minimal extent of oxidation. Dispersivity of the samples changed in the range of 5 to 23 μm .

Results And Discussion

The following characteristics of fire and explosion hazard of AH samples were determined with the help of standard procedures described in GOST 12.1.044-89 /1/: spontaneous ignition temperature (T_{si} , $^{\circ}\text{C}$), low concentration limit of flame propagation (LCLFP, $\text{g} \cdot \text{m}^{-3}$), maximal explosion pressure (P_{max} , kPa); maximal rate of pressure rise (dP/dt , $\text{MPa} \cdot \text{s}^{-1}$).

Besides there were determined the impact pyrophorus ability (E_{imp} , J), energy of ignition by the glowing wire (E_{ign} , J); rate of combustion front propagation along the powder surface (V_{com} , $\text{mm} \cdot \text{s}^{-1}$).

The techniques of determination of E_{imp} , E_{ign} , V_{com} are described in article /2/ in detail, they are qualitative methods allowing to compare different materials by the extent of their pyrophorus ability and the dynamics of combustion front propagation on the basis of quantitative results of tests.

Derivatographic analysis showed that decomposition of aluminum hydride accompanied by the hydrogen release occurs in the temperature interval of 160 – 200 $^{\circ}\text{C}$. A sharp decrease of the samples mass and the peak of the endothermic effect on DTA curve testify to it (it agrees with the positive value of AH decomposition enthalpy).

The decrease of the AH sample mass in air substantially exceeds the total mass of hydrogen released. It is connected with the fact that AH decomposition is accompanied by the particles cracking and the release of hydrogen which takes away fine powder particles.

The decrease of the AH sample mass in atmosphere of nitrogen and argon is somewhat less than that in air. It is connected perhaps with the partial fritting of the surface layer of AH powder and the decrease of its particles exportation.

It should be emphasized that in the atmosphere of nitrogen the interaction of aluminum (which has formed after sample thermolysis) with nitrogen proceeds much more intensively in comparison with the process of aluminum oxidation in the atmosphere of air. The intensive interaction of aluminum (formed as a result of AH decomposition) with nitrogen originates at temperature of 580 $^{\circ}\text{C}$ before its melting. The process of intensive interaction of aluminum with nitrogen contained in air begins after its melting at the temperature of 650-660 $^{\circ}\text{C}$. May be, the difference of the protective properties of aluminum nitride and oxide is the cause of this.

A comparison of derivatograms of aluminum powder of ACD-4 type obtained in air with that of AH confirms that aluminum which is formed at AH decomposition is characterized by an elevated reactivity.

It should be stressed that the rate of interaction of aluminum with nitrogen at the temperature of 580 $^{\circ}\text{C}$ allows to admit the possibility of spontaneous ignition of AH in the atmosphere of nitrogen at this temperature.

Analysis of the derivatograms and the literary data available relating to the mechanism of AH decomposition allow to suppose the following mechanism of its ignition.

Thermolysis of AH is a characteristic topochemical reaction which proceeds through the stage of formation of decomposition nuclei (phases of the metal aluminum) which are the potential centers of origin of the reacting nuclei.

As the rate of hydrogen release decreases, the surface of the metal particles becomes accessible for atmospheric air.

Meanwhile the prerequisites are created promoting the loss of thermal equilibrium because the reaction of oxidation is an exothermic one and the growth of the nuclei proceeds according to the self-catalyzed branched mechanism.

Availability of the exothermic peaks on DTA curve after cessation of decomposition and comparison with the standard value of T_{si} of AH ($\approx 230^\circ\text{C}$) confirms that this is the moment of sample ignition.

Maximal values of indices of fire and explosion hazard of AH samples are presented in the Table.

Table

$d_{av}, \mu\text{m}$	E_{imp}, J	E_{ign}, J	LCLFP, $\text{g} \cdot \text{m}^{-3}$	MEHOC, % vol.
6,3	17	93	35,2	0,8
23,2	2,5	59,9	12,3	4,5

T_{si} was 230°C ; $P_{exp} = 1840 \text{ kPa}$; $dP/d\tau = 366,7 \text{ MPa} \cdot \text{s}^{-1}$.

Analysis of the obtained results permits to reach the following conclusions. Samples of AH powders with pure unoxidized surface have extremely high characteristics of explosion hazard:

High value of explosion pressure (1840 kPa) exceeds usual values of pressure typical for metal powders explosions, moreover maximal value of explosion pressure was not achieved because of limited size of the test apparatus. Calculation of explosion parameters of AH powder in air shows that maximal value of explosion pressure in air can be 6800 kPa under adiabatic conditions.

A chemical analysis of the combustion products after explosion of air suspension of AH having concentration of $1000 \text{ g} \cdot \text{m}^{-3}$ showed that the gas phase consisted of hydrogen and nitrogen. Oxygen is not available in the gas phase. Solid combustion products have variable composition which can be described by the following formula $\text{AlN} \cdot (\text{Al}_2\text{O}_3)_n$, where $n = 2,3-6,0$; Rate of explosion pressure rise amounted to $366,7 \text{ MPa} \cdot \text{s}^{-1}$. The explosion was accompanied by a typical metal click. It is quite possible that this process can proceed in the regime of detonation under real conditions. In case of technological equipment destruction after the explosion a contact of air with released hydrogen will take place and a second explosion of hydrogen-air mixture will occur.

Results of derivatographic and chemical research allow to assume the following

mechanism of combustion of powdered AH air suspension :

- AH particles crack in the combustion front (photos of this process taken under microscope also confirm this), their specific surface substantially increases;

- finely dispersed particles of aluminum formed are very active, pyrophorus and easily react with oxygen and nitrogen of air;

- hydrogen released during AH decomposition facilitates propagation of air suspension combustion, growth of volume and pressure in gas medium.

Along with the cracking of AH particles the effect of hybrid mixtures formation should be taken into account. They increase the explosibility of AH in comparison with powders of combustible metals /5/.

Explosion hazard of AH air suspension depends strongly on particles dispersive ness. Increase of particles dimensions (from 5 to 20 μm) leads to abnormal decrease of LCLFP (from 40 to 12 $\text{g} \cdot \text{m}^{-3}$). As AH particles dimensions decrease MEHOC (minimal explosion hazardous oxygen concentration) decreases. At dispersiveness of the particles of 6-9 μm MEHOC of AH air suspension amounts to only 0,8% vol. Approximation of the obtained regression dependence shows that at dispersiveness of AH particles of 2-3 μm an explosion of its air suspension is possible in pure nitrogen.

Different influence of AH particles dispersiveness on LCLFP and MEHOC (with due regard to the results of chemical analysis of the combustion products) can be explained also by the fact that the combustion proceeds under different conditions: LCLFP is determined at excess of O_2 , and MEHOC – at shortage of O_2 .

Conclusions

The test results obtained allow to explain extremely high explosion hazard of air suspensions of aluminum hydride powder.

References

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