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Change in thermochemical properties of aluminum nanopowders upon irradiation with electron beam and microwave

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Abstract. *In this work, aluminum nanopowder samples were irradiated with electron beam and microwave radiation of varying dose to ascertain their effect on thermophysical properties of metal powders. The results from the differential thermal analysis of the irradiated samples shows the highest value of thermal heat of oxidation (13678J/g) in the sample irradiated with microwave of (100J/50Hz) with a corresponding highest peak temperature of oxidation (625°C). Based on the obtained experimental results, no correlation was observed between oxidation onset temperature and thermal effect of oxidation.*

Key words*: Nanopowders, irradiation, aluminum, thermal heat of oxidation.*

Introduction

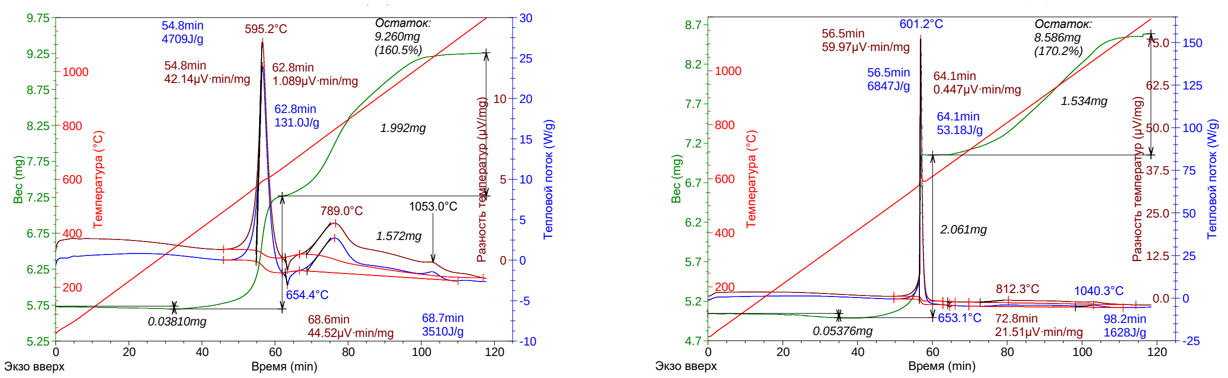
The phenomenon behind the principle of radiation interaction with matter makes the application of irradiation technique in the modification of metal nanopowders more appealing. The evolution of irradiation technology gives rise to targeted modification of nanostructures resulting in the creation of new, hybrid and novel materials of desired properties within the nanometer range [1]. The structural changes and absorbed energy that take place are measured and analyzed using several methods such as differential thermal analysis (DTA) [2, 3]. DTA is used to determine the amount of energy stored in metal nanoparticles [4], and the accompanying changes in their thermochemical parameters such as thermal stability, change in thermal effect of oxidation and the recombination energy of certain defect types [5].

Research methods

The samples of aluminum nanopowder produced from electric explosion of aluminum wire were used in this experiment. To compare the effect of the two forms of radiations, some samples were irradiated with pulsed electron beam of 100J dose at 250 keV while others were irradiated with microwave irradiation of varying energy, frequency and dose. The irradiated samples were analyzed using DTA method, which was carried out using SDT Q600 TA instrument. In addition to the DTA values, the integrated TA instrument gave the outputs for differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) all in a single thermogram. This allowed for a speedier examination and expediency when analyzing other properties such as change in temperature, weight gain or weight loss.

Results

The experimental results and calculated values regarding the thermal parameters of the samples after exposure to electron beam and microwave irradiations were obtained as shown in Table 1. From the thermograms of the differential thermal analysis generated (Figure 1), the specific thermal effect of the non-irradiated sample (1) was found to be 8219 J/g, the oxidation onset temperature was 480 °C and the peak oxidation temperature was 595.2 °C. The exothermic oxidation peak was broad, which was an evidence of gradual oxidation rate. The non-irradiated sample melted at a temperature of 654.5 °C, which was within the range of the theoretical value (660 °C) with its degree of oxidation being 61.50 % (Table 2). Compared with the findings in [6], the temperature for onset of oxidation was increased by 25 °C when sample (2) was irradiated with electron beam, as shown in Figure 1b. Similarly, its specific thermal effect of oxidation increased by 3.1 %, which is of smaller margin compared to the non-irradiated sample. However, the degree of oxidation increased by 14.2 %, the melting point remained within the same range and the peak oxidation temperature was recorded as 601.2 °C, with an increase of 9 °C.



(a) *(b)*

Fig. 1. Thermograms of aluminum nanopowder (a) before and (b) after irradiation with electron beam 100J/250KeV

Table 1

Thermochemical parameters of aluminum powders after exposure to different radiations

SAMPLES	WEIGHT (mg)	DOSE	HEAT EFFECT 1 (J/g)	HEAT EFFECT 2 (J/g)	ENDO EFFECT (J/g)
1	5.7690	0	4709	3510	131.0
2	5.0450	100J/250KeV	6847	1628	53.18
3	5.5800	100J/50Hz	8881	4797	43.67
4	5.5040	100J/25Hz	6373	6517	72.01
5	5.7500	300J/25Hz	6171	6781	62.44

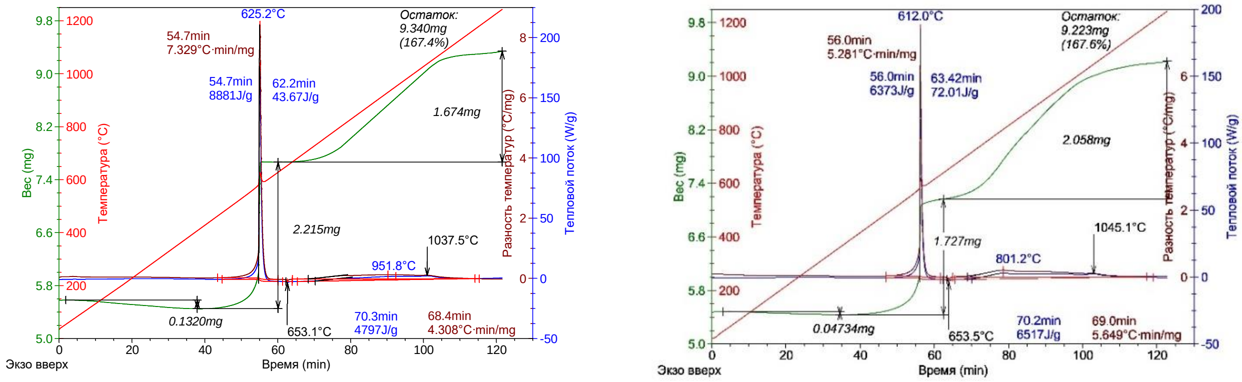
Table 2

Thermochemical parameters of aluminum powders after exposure to different radiations

SAMPLES	THERMAL EFFECT OF OXIDATION (J/g)	OXIDATION ONSET TEMPERATURE (^{0}C)	PEAK TEMPERATURE OF OXIDATION (^{0}C)	DEGREE OF OXIDATION (%)	WEIGHT GAIN (g)
1	8219	480	595.2	61.5	3.491
2	8475	505	601.2	70.2	3.541
3	13678	460	625.2	67.3	3.760
4	12890	485	612.0	68.1	3.719
5	12952	480	619.8	65.1	3.746

However, subjecting the aluminum nano-powder to microwave radiation with varying doses of 100J/50Hz (Sample 3), 100J/25Hz (Sample 4) and 300J/25Hz (Sample 5) led to variations in the thermal properties of aluminum powders. The highest specific thermal effect of 13678 J/g was observed under irradiation of sample 3, as shown in Figure 2b. This value is 66.6 % higher than the specific thermal effect for the non-irradiated sample. This value is the maximum value of the specific thermal effect in this experiment with a corresponding peak oxidation temperature of 625 °C.

A keen observation of the TGA curves shows a rapid weight gain post first oxidation stage in the 3 samples (1, 4 & 5) while the weight gain in samples (Sample 2 & Sample 3) is gradual. Sample 3 has the highest weight gain (3.76 g) as shown in Table 2. Fluctuation in the temperature of onset of oxidation in aluminum nanopowders as reported in [6] was caused by the partial reduction of metal ions in the oxide shell. This reduction was succeeded by the formation of sub-oxides, as found in pure aluminum nanopowder samples. In contrast, we may conclude that the samples in this experiment were of pure aluminum powder. As a result, the oxidation rate was rapid as evidently seen in the sharp narrow exothermic peaks, which led to an increase in the temperature of onset of oxidation. Furthermore, it is observed that the highest degree of oxidation (70.2 %) was recorded after irradiation by electron beam. This coincides with the highest temperature of the onset of oxidation (505 °C).



(a) *(b)*

Fig. 2. Thermograms of aluminum nanopowder after irradiation with (a) microwave (100J/50Hz) and (b) with microwave radiation dose (100J/25Hz)

Conclusion

In the course of this work, it has been confirmed that irradiation with microwave enhances thermal heat of oxidation and increases the degree of oxidation in comparison to electron beam radiation. In contrast, electron beam when administered raises the temperature of onset of oxidation to the highest value owing to the highest degree of oxidation.

In light of this, the discoveries regarding increased thermal heat of oxidation in aluminum nanopowder may prove useful in a number of industrial applications for aluminum powder as a highly energetic material, such as solid rocket propellants, pyrotechnics and explosives, wherein quick and effective energy release or reaction kinetics are required. Evidently, higher rate of energy release from energetic materials results from increased thermal heat of oxidation, which consequently increases their potency and efficiency.

References

1. Tanaka S.I. Control and Modification of Nanostructured Materials by Electron Beam Irradiation // Quantum Beam Science. – 2021. – Vol. 5, № 3. – P. 23.
2. Biswas P., Wu C.Y. Nanoparticles and the environment // Journal of the air & waste management association. – 2005. – Vol. 55, № 6. – P. 708–746.
3. Gunther B.H. Nanoscale Metal Powders Production and Applications // Journal of Powder Materials. – 2002. – Vol. 9, № 6. – P. 409–415.
4. Il'in A. P., Root L.O., Mostovshchikov A.V. The rise of energy accumulated in metal nanopowders // Technical Physics. – 2012. – Vol. 57. – P.1178–1180.
5. Mostovshchikov A.V., Ilyin A.P., Zakharova M.A. Structural and energy state of electro-explosive aluminum nanopowder // Key Engineering Materials. – 2016. – Vol. 712. – P. 215–219.
6. Mostovshchikov A.V. et al. Parameters of iron and aluminum nano and micro powder activity upon oxidation in air under microwave irradiation // Technical Physics. – 2018. – Vol. 63. – P. 1223–1227.