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Plasma-induced melting and microfiber formation from zeolite-containing mineral waste

Viktorija Grigaitienė, Mindaugas Milieška, Romualdas Kėželis, Vitas Valinčius, Vilma Snapkauskienė

Plasma Processing Laboratory, Lithuanian Energy Institute, Kaunas, Lithuania

INTRODUCTION & AIM

Zeolite-containing waste generated during the petroleum fluid catalytic cracking (FCC) process has a large-volume aluminosilicate by-product of the oil refining industry. After losing catalytic activity, these materials become environmentally problematic and are typically disposed of despite their valuable mineral composition. Because spent FCC catalysts contain high amounts of SiO_2 and Al_2O_3, they can serve as a promising secondary raw material for the production of advanced ceramic or glass-based materials. The manufacture of refractory and high-temperature insulation materials usually requires energy-intensive thermal processing and multiple technological steps. Plasma technology offers such an opportunity combining melting and product formation in a single process due to its extremely high temperatures and high-energy gas flows. In plasma systems, the thermal and kinetic energy of the plasma jet can rapidly melt mineral particles and transform the molten material into products such as fibers, granules, or fine particles. The interaction between plasma jets, dispersed particles, and molten materials plays a crucial role in determining the morphology and quality of the resulting products. Therefore, further experimental studies are required to better understand these processes and to develop efficient technologies for converting mineral waste into valuable fibrous materials.

METHOD

Experiments were performed using a low-temperature atmospheric-pressure plasma spraying system developed at the Lithuanian Energy Institute. The setup consisted of a linear direct-current (DC) plasma torch, gas supply and monitoring system, cooling system, and a control unit for continuous data acquisition (Fig. 1). The plasma torch operated with air as the plasma-forming gas at powers of 70–80 kW, producing plasma jets with mean outlet temperatures of 2000–2800 K and velocities of 900–1500 m/s. Zeolite-containing powder particles (≤60 μm) were injected into the plasma jet through a plasma chemical reactor connected directly to the plasma torch anode.

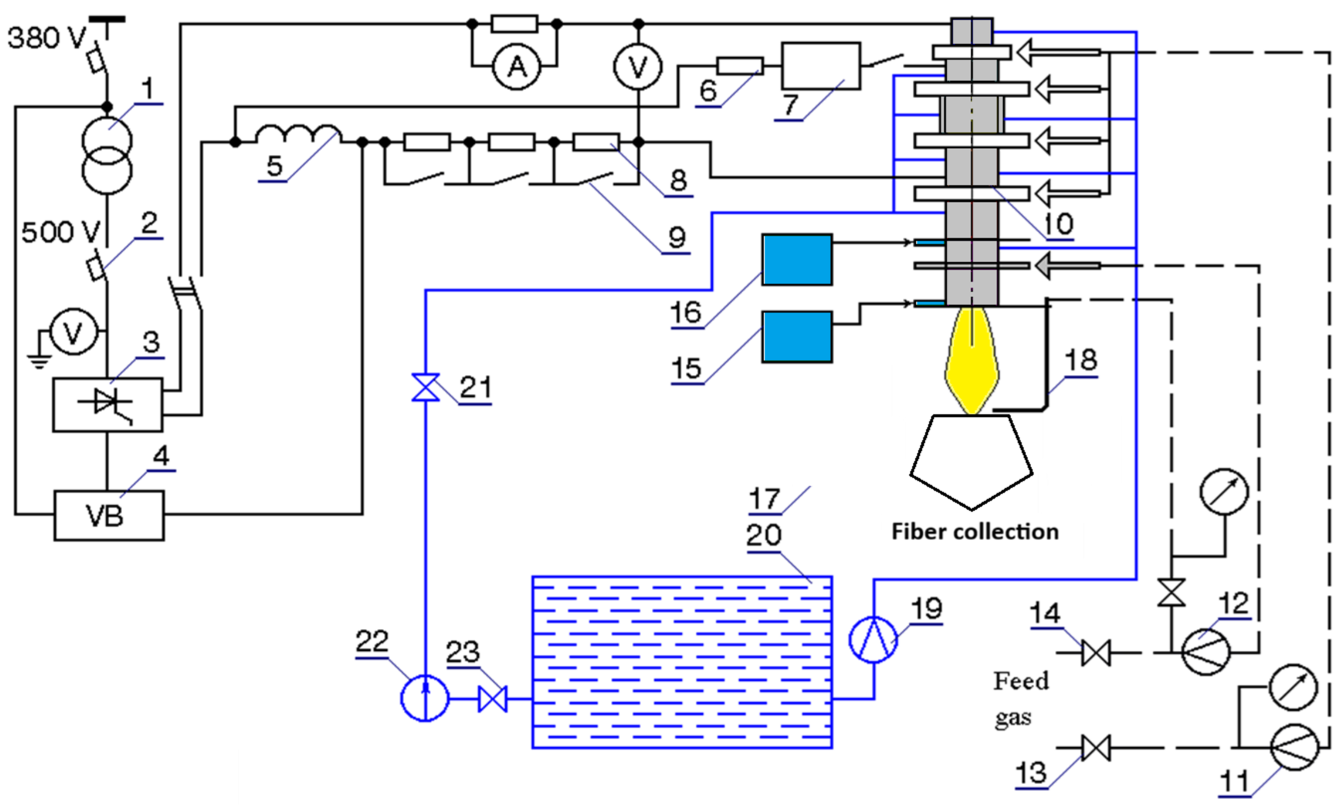

Fig.1. Schematics of experimental set-up.

Table 1. Process parameters for mineral fiber production

Regime series	1	2	3
Diameter of exit nozzle, mm	10	13	15
Flow velocity, m/s	1515	1092	898
Power, kW	67	69	74
Plasma forming gas flow rate, g/s	14.8	14	14
Flow rate of propane-butane, g/s	0.5	0.5	0.5
Mean-mass gas temperature in the reactor exhaust cross section, K	1892	2522	2734

As dispersed material for the plasma treatment was powder of waste oil-cracking catalyst (zeolite) with following chemical composition [mass %]: Al_2O_3 – 40.9, SiO_2 – 55.2, Fe_2O_3 – 0.9, TiO_2 – 1.4, CaO – 0.5, MgO – 0.49, Na_2O – 0.2. The particle size was approximately 50 μm, density - 830 kg/m^3.

The influence of plasma processing conditions on fiber formation was evaluated by varying plasma jet parameters such as gas flow rate, plasma temperature, and reactor geometry. The morphology and size distribution of the obtained fibers were examined using scanning electron microscopy (SEM), while X-ray diffraction (XRD) analysis was performed to investigate structural changes in the material.

RESULTS & DISCUSSION

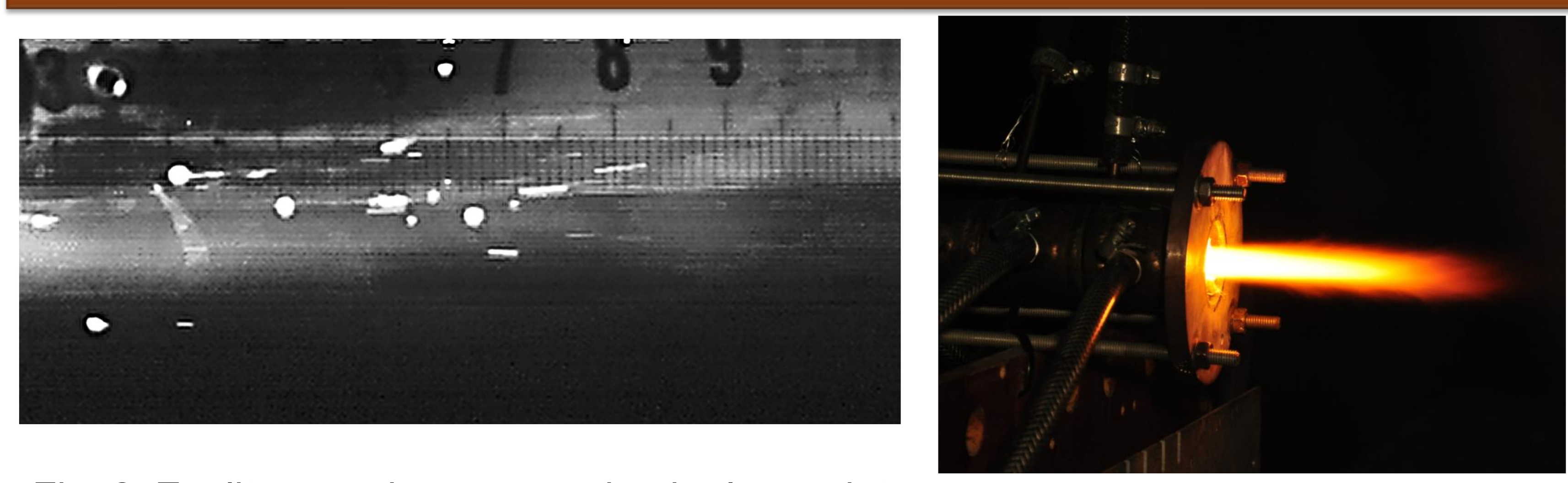

Fig. 2. Zeolite spraying process in air plasma jet

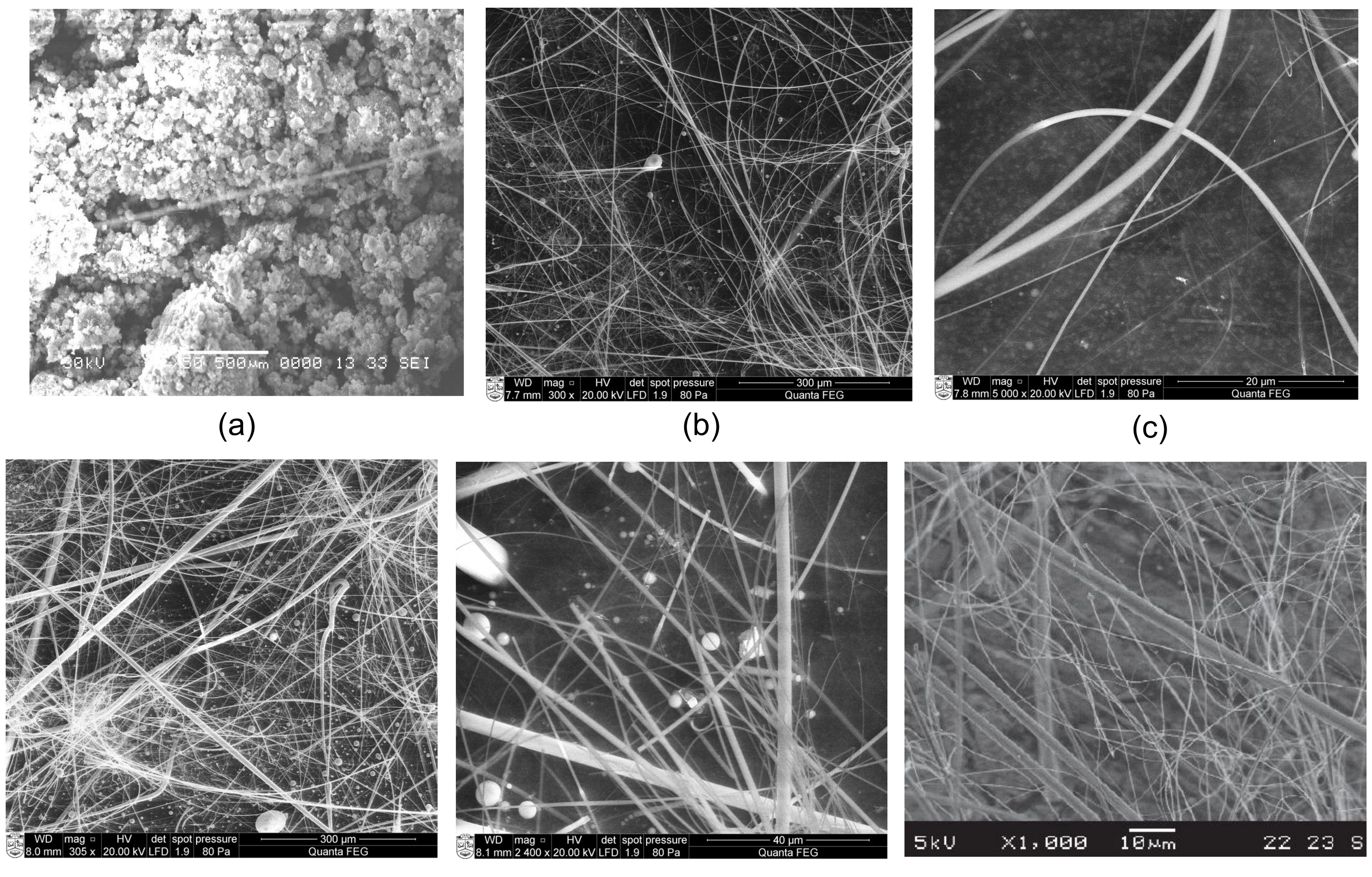

Fig. 3. Morphology of zeolite fibers, produced by different spraying regimes. Raw zeolite powder (a), the outlet section diameter is 10 mm (b, c), 13 mm (d, e) and 15 mm (e).

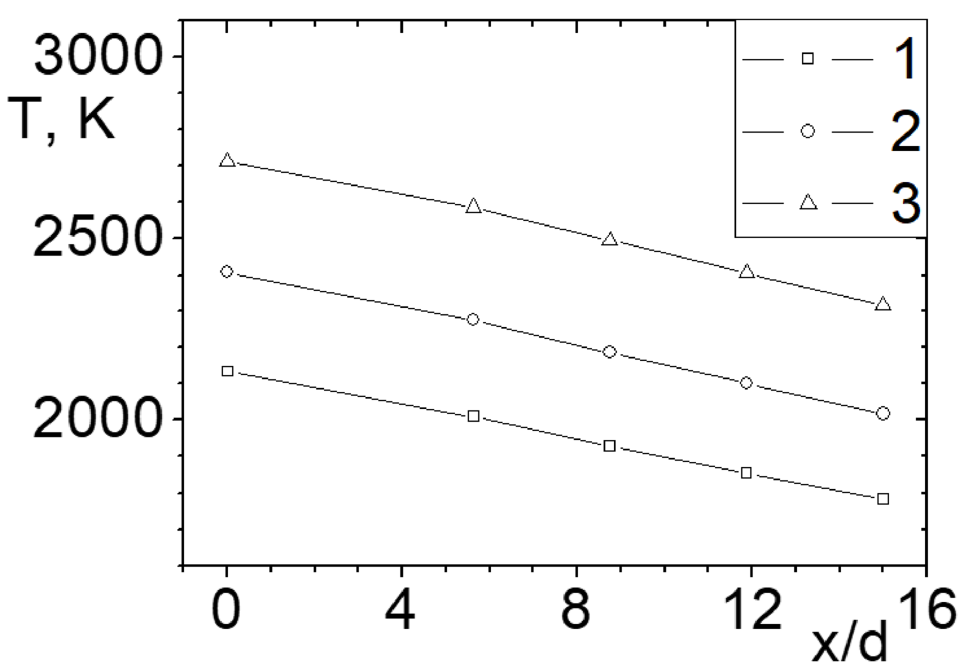

Fig. 4. The plasma flow temperature distribution in the length of reactor channel (15 mm of diameter) at different PT power input. 1 – 56 kW, 2 – 66 kW, 3 – 81 kW

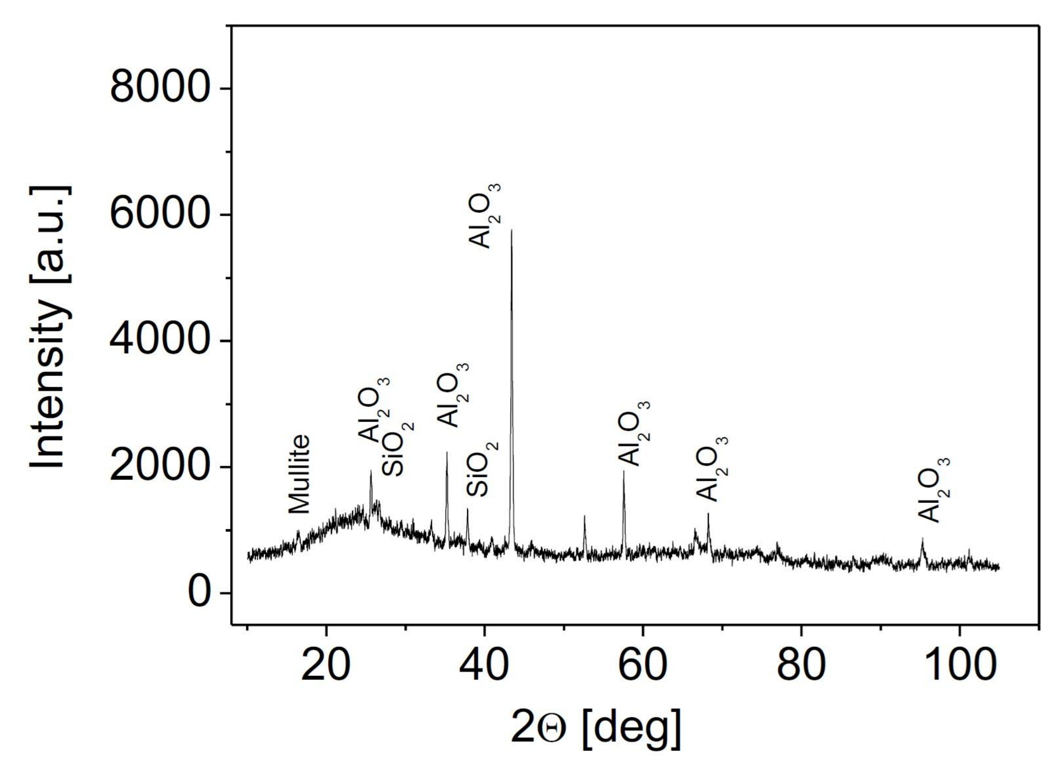

Fig. 5. The XRD patterns of prepared zeolite fiber.

CONCLUSION

The study demonstrates that atmospheric-pressure plasma processing is an effective method for melting zeolite-containing mineral waste and converting it into aluminosilicate microfibers. High-temperature plasma jets with temperatures above 2500 K enable rapid melting of injected zeolite particles, while the high-velocity flow promotes aerodynamic stretching of molten droplets, leading to fiber formation. The addition of propane–butane gas increases radiative heat transfer in the reactor and intensifies the melting process, improving the efficiency of fiber production. The morphology and quality of the produced fibers depend strongly on plasma operating parameters, reactor geometry, particle size, and injection conditions.The obtained fibers had diameters in the range of 0.5–5 μm and lengths up to 0.07 m, demonstrating the potential of plasma technology for converting mineral waste into high-value fibrous materials suitable for high-temperature insulation and advanced material applications.