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FLAME SYNTHESIS OF SUPERHYDROPHOBIC SOOT SURFACES

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Abstract

Preparation of hydrophobic materials is an important field. We synthesize superhydrophobic soot through the combustion of propane and the pyrolysis products of polyethylene waste on surfaces. The influences of an electric field and of metal catalysts are examined.

1. Introduction

Soot is product, which produce in a large volume and widely used to modify the mechanical, electrical and optical properties of structural materials in the production of elastomers, dyes, dry power sources, etc. The main criterion their using are desired properties of soot. Therefore, the development of new method of process control soot formation with giving its final properties is an important scientific problem. Decision of the given problem will significantly reduce the costs for the design and optimization of energy systems and processes based on combustion and pyrolysis of hydrocarbons. As a result, reduce the cost of producing the desired products and reduce harmful stress on the environment. In combustion of hydrocarbon fuels soot particles are a by-product of combustion. However, if burn fuel under certain conditions, it will possible to produce soot with desired properties [1, 2, 3].

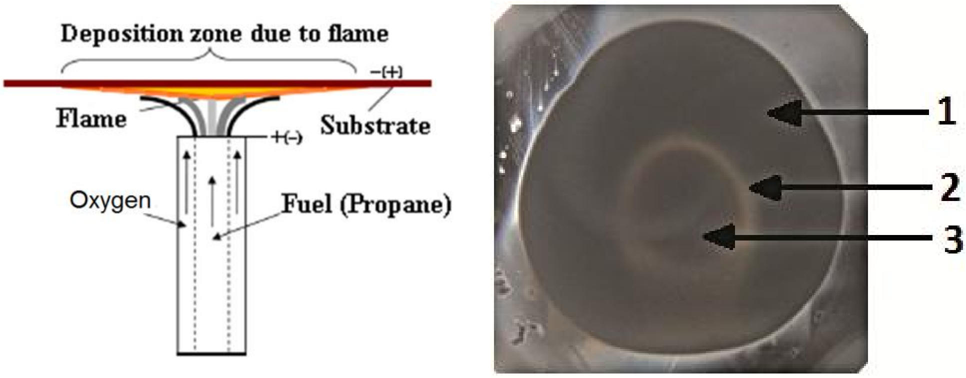
Hydrophobic materials and composites are widely used in industries for construction, textiles, instruments and paint production. Flame synthesize of hydrophobic soot, which has many practical applications, e.g. as a hydrophobic composite material based on sand [4]. The synthesis of superhydrophobic soot includes several intermediate stages [5]. Intensive soot formation occurs in hydrocarbon flames that have limited access to air or when materials thermally decompose in an oxidant deficient ambient. The rate of hydrocarbon thermal decomposition depends on temperature and can be enhanced by combustion or catalysis. A high temperature of flame can also produce with local influence electric field. Thus, both catalysts and an applied electric field allow control over the size and structure of the resulting soot particles.

2. Experimental methods of approach

In experiments for synthesis superhydrophobic soot were used two kinds of fuel, such as propane and polyethylene waste. To collect the superhydrophobic soot were used silicon substrate for propane and the soot collector of drum type was used for polyethylene waste. The burner configuration is identical to one used previously [6].

Fig. 1a shows schematic illustration of burner device for producing superhydrophobic soot during combustion of propane. A silicon (Si) disk is placed 2 cm above the burner and exposed to a flame for 4, 6 and 10 minutes. Optimal conditions of synthesis are flow rate of propane is 150 cm^3/min, and oxygen is 310 cm^3/min. This results in the deposition of the carbon film shown in Fig. 1b.

The deposition is differentiated into the three zones which shown in Fig. 1b, i.e., (1) a central gray area that is (2) surrounded by a brown zone, which (3) is enclosed within a black sooty outer zone. In the case of applying an electric field, we investigated the influence an electric field of 1 kV applied between the substrate and the burner. The substrates are exposed to the soot flame with and without the applied electric field, in both cases for 10 minutes.



a b

Fig. 1. Scheme of installation and a photograph of the substrate: a) schematic illustration of burner device; b) a silicon disk with a hydrophobic coating at 4 min exposure to a propane/oxygen flame with flow rate 150/310 cm^3/min, showing of three deposition zones.

In case of using the catalyst we use a cellular catalyst composed of nickel plates. For this purpose, a nickel sheet of 99.9 % purity is cut into a 5 mm x 1 cm rectangle. These rectangles are combined to form a square honeycomb structure of 5 mm depth. The results show that the optimal distance for the catalyst to be placed is 2 cm away from the surface of the burner in the area of the flame where vigorous chemical reactions occur.

We also investigated if polyethylene waste produces superhydrophobic soot, since there is increasing worldwide demand for reuse of this waste. Polyethylene waste exposed to thermal decomposition to produce gaseous hydrocarbons. These hydrocarbons are carried away stream of argon which purged the reactor. Combustion of waste gases results in the formation of superhydrophobic soot. Fig. 3 shows a photograph of the deposition process of superhydrophobic soot on the soot collector drum type during combustion of decomposition products of polyethylene waste.

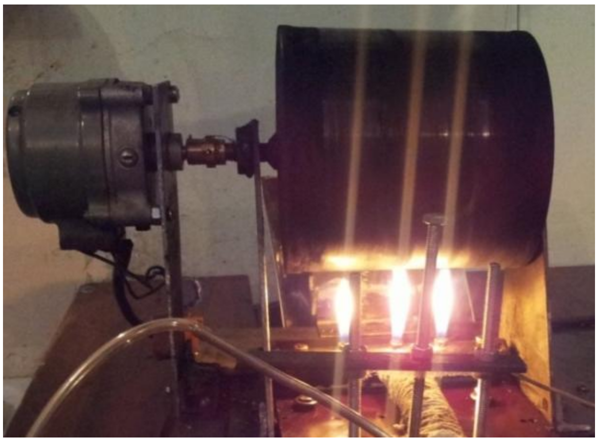


Fig. 3. Image of the experimental installation for synthesis superhydrophobic carbon black during combustion of pyrolysis products of polyethylene waste

Again, experiments are performed by applying an electric field and using a catalyst with the apparatus shown in Fig. 3. Soot particles are deposited on the surface of a stainless steel cylinder that is rotated at 1 rotation per second. The 1 mm diameter nozzles carry a feed gas flow rate of 425-500 cm^3/min. An electric field voltage is applied in the range 0.01-1 kW. Depending on the polarity of the applied voltage, the cylinder may serve as an anode or cathode. The soot collected on the cylinder surface is removed with a surface mounted scraper and collected in a container. The apparatus has the ability to automatically collect superhydrophobic soot, and measure the temperature of the deposition surface and the contact time of the flame with the soot collector. The formation and deposition of soot particles is sensitive to thermal energy losses. Here, the cylinder surface serves as a heat sink where its rotation speed controls the heat loss. For our conditions, the surface temperature of cylinder is stabilized at ≈ 180˚C. The optimal distance for the catalyst to be placed is 2 cm above from the surface of the burner.

The deposit of soot is analyzed for hydrophobic properties. For this purpose were determined the contact angle. The essence of this method consists in measuring the contact angle of water droplets by a microscope. Contact angle characterizes the interaction of water droplets with surface of superhydrophobic soot. If the contact angle over 150º surface is superhydrophobic. To determine the structure of the resulting dispersion and soot particles, the samples are examined with a transmission electron microscope.

3. Results and discussion

Fig. 4 shows the behavior of water droplets placed on the surface of a quartz plate coated with a layer of a hydrophobic soot during combustion propane and pyrolysis products of polyethylene waste with a nickel catalyst. As seen from the photographs angle for water drops is 150º from layer of a hydrophobic soot during combustion propane (Fig. 4a) and 165º from layer of a hydrophobic soot during combustion pyrolysis products of polyethylene waste (Fig. 4b).

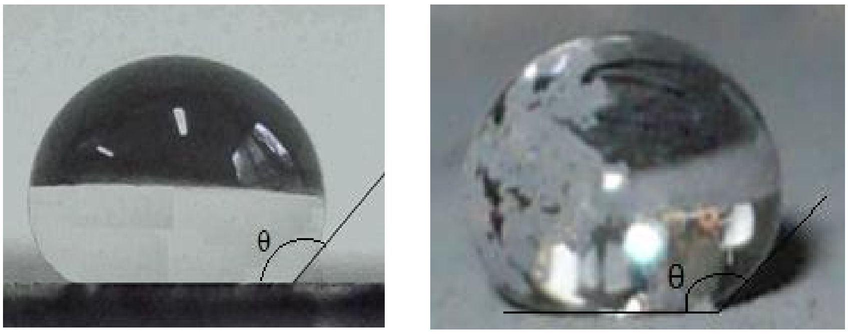


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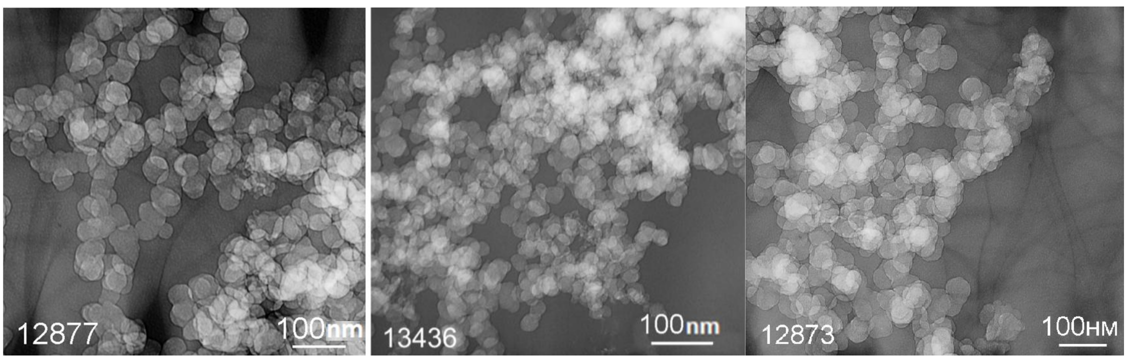
Fig. 4. The behavior of water droplets placed on the surface of a quartz plate coated with a layer of hydrophobic soot: a - drop of water on the superhydrophobic carbon during combustion propane with a nickel catalyst; b - water drop on surface soot obtained during combustion of pyrolysis products of polyethylene waste with a nickel catalyst.

Fig. 5 shows electron micrographs of soot during combustion products of the catalytic pyrolysis of plastic waste: without additional influences (Fig. 5a); with an applied electric field 1 kV (Fig. 5b); with a nickel catalyst (Fig. 5c).



a b c

Fig. 5. Electron micrographs of soot during combustion products of the catalytic pyrolysis of plastic waste a) without additional influences; b) with an applied electric field 1 kV; c) with a nickel catalyst

The central (1) and middle zones (2) (Fig. 1 b) contain carbon nanobead chains that are 15-30 nm long in the absence of an electric field. Regardless of combustion conditions, the outermost Zone 3 contains coagulated soot aggregates of sizes between 30-50 nm. When an electric field is applied, soot particles have a small diameter spread in the range 10-20 nm. Soot formed from smaller soot particles produce a chain structure while larger soot aggregates into irregular shape soot particles. The most soot is produced in a propane flame when the substrate is placed 1.8-2.2 cm from the burner. Electric fields have an "electro gas dynamic" impact on sooting, i.e., the strength of an electric force must exceed the force inducing convective motion. Upon increasing the electric field beyond 300 V, the positively and negatively charged incipient soot particles become balanced. They now approach and collide to form chain-like structures, which increases the granularity of soot.

In the case of applying an electric field of 1 kV during combustion of propane (Fig. 5b) the dimensions of the particles are ≈ 30-40 nm, there is significant chain formation and tertiary structure, and the wetting angle is larger than 165°, i.e., the deposit is superhydrophobic. Fig. 5b presents electron micrographs of soot samples through the catalytic pyrolysis of polyethylene waste. When using a nickel catalyst the soot particles also have spherical shapes with 20-30 nm sizes, chain structures but a smaller size spread, resulting in a wetting angle above 165°, also superhydrophobic.

4. Conclusions

Application of an electric field during the combustion of propane has a significant impact on the structure and morphology of the resulting soot particles. The size of the soot particles is reduced, granularity increased and the size spread reduced. An applied electric field voltage over 300 volts also reduces the size of soot particles, which positively affects their hydrophobic properties. A nickel catalyst has a significant impact on the structure of the resulting soot, and induces high dispersion and structuring.

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