ENERGETIKA. 2010. T. 56. Nr. 2. P. 126–131


# Realization and analysis of inorganic metal oxide plasma melting and fibrillation process

**Mindaugas Milieška,**

**Romualdas Kėželis,**

**Vitas Valinčius,**

**Vladas Mėčius**

*Plasma Processing Laboratory,*
*Lithuanian Energy Institute,*
*Breslaujos 3,*
*LT-44403 Kaunas,*
*Lithuania*
*E-mail: milieska@mail.lei.lt*

The proposed new plasma technology for the production of fiber from inorganic metal oxides overtakes traditional sustaining technologies due to the simplicity of processing and a good quality of the obtained product. The paper contains a description of a uniflow plasma chemical reactor designed for melting and fibrillation of ceramic materials, an analysis of its optimal exploitation conditions at atmospheric pressure and a characterization of the final product obtained during realization of the plasma fibrillation process.

Air was used as the plasma-forming gas and propane-butane as the additional supporting gas. The power of the plasma torch was in the range 65–69 kW. Mineral fiber was manufactured from different dolomite and quartz sand mixtures. Dolomite content in the mixtures varied from 25% to 35%, as the purpose of the experiment was to elucidate the influence of dolomite content in the mixtures on the quality of the obtained mineral fiber. The temperature and velocity of gas leaving the reactor was 2 316–2 516 K and 500–530 m/s, respectively. Then a mixture of 60% of quartz sand and 40% of dolomite was used with two different designs of the plasma chemical reactor to determine the influence of the velocity of flow leaving the reactor on the quality of the obtained mineral fiber. The temperature of the flow was 2 900–2 970 K, and its velocity increased from 794 m/s to 1 759 m/s.

The structure and morphology of mineral fiber were examined by scanning electron microscopy (SEM). The process of fiber formation was analyzed by visualization using a CCD camera.

Fibers have been formed by kinetic energy of the flow. The mechanism of fiber formation is explained. Mineral fiber produced employing the plasma fibrillation process is resistant to high temperatures (up to 1 300 °C); the diameter of the fiber filament doesn't exceed 2–5 µm. It is more suitable for the production of high temperature or noise isolators, catalysts or filters.

**Key words:** plasma, plasma-chemical reactor, mineral fiber

## 1. INTRODUCTION

Mineral fiber is the general name for many kinds of inorganic insulation materials made of inorganic metal oxides. There are three categories of mineral fiber according to maximum temperature endurance. These are glass wool (from 230 °C to 250 °C), stone wool (700 °C to 850 °C) and ceramic fiber (up to 1 200 °C) [1].

Ceramic fibers, made of inorganic metal oxides because of their light weight, thermal shock resistance, and strength, are useful in a number of industries as a high temperature and noise insulators, filters and catalysts. Materials used for manufacturing high-temperature mineral fiber must be resistant to high temperatures and fire, display a low thermal conductivity and chemical stability. The product must be relatively cheap and environmentally friendly so that it would be affordable by the average industry. Such properties are displayed by raw materials like quartz, dolomite, zeolite, granite, basalt, limestone, etc.

There exist several production methods for manufacturing mineral fibers, with a wide variation of the quality and quantity of the final product. The most commonly used mineral wool production process is the fibrillation of molten bulk on rapidly rotating spinning discs. The molten substances enter through a siphon neck into a homogenization reservoir, pass a weir and directing channel and under gravity falls onto a rotating disc of the spinning machine. After this, the mineral wool reaches the conveyor belt of the secondary mineral wool layer where it is thermally treated and finalized to the selected density, thickness and size [1].

This method requires quite a complex equipment and uninterrupted fabrication technologies. Upcoming demands for high quality and new functionality products often mean that traditional production methods are finding it increasingly difficult to produce refractory or compact fiber for wide-range applications. The on-stream technological process is required for these purposes. So, traditional technologies are unusable for high temperature resistance fiber production [2].

## 2. METHODOLOGY

At the Plasma Processing Laboratory of the Lithuanian Energy Institute, a specific plasma-chemical jet reactor (Fig. 1) with a linear step formed DC plasma torch (PT) 65–69 kW of power capacity for the melting and fibrillation of inorganic metal oxides at atmospheric pressure was designed. Air was used as the plasma-forming gas and propane-butane as the additional supporting gas to increase heat flux from plasma flow to dispersed particles. Propane-butane also improves the balance of the oxygen–nitrogen mixture in plasma, simultaneously increasing the temperature inside the reactor.

The uniflow plasma chemical reactor connected to a plasma torch consists of four sections 0.015 m diameter and 0.05 m in length, made of stainless steel and cooled by water. Such design enables, if needed to change the length of the reactor. If necessary, the diameter of the outlet exhaust can be reduced from 0.015 m to 0.010 m. If the diameter of the outlet exhaust is smaller, the velocity of plasma and dispersive particles leaving the reactor is higher. In some cases it exceeds the velocity of sound [3].

## 3. RESULTS AND DISCUSSION

Dolomite content in mixtures with quartz sand influences the quality of the obtained fiber, so three types of dolomite and quartz sand mixtures were prepared for melting and conversion into fiber (Table 1). These materials were selected because of their comparatively high melting temperature, suitable viscosity, low cost and prevalence. The dolomite content in the mixtures varied within 25–35%. The composition of mixtures and the range of basic parameters in the plasma-chemical reactor are presented in Table 1. The diameter of the outlet exhaust was 0.015 m.

Table 1 shows that all mixtures of dolomite and quartz sand were melted and converted into fiber in similar conditions. Therefore, it is possible to analyze the structural and morphological differences of the obtained mineral fibers (Fig. 2).

As one can see in Fig. 2, despite the temperature, a plasma flow of the filaments of a comparatively higher diameter leaving the reactor in the bulk has been observed. The average diameter of the filaments was approximately 300 nm – 5 μm, and the average length was about 10 cm. As in the plasma torch the voltage arc current and the plasma forming gas flow rate were almost constant, the diameter of filaments decreased with increasing the melting temperature of the mixture. So, a thinner fiber was obtained in the case when the content of quartz sand in the mixture was higher. The possible reason for this fact seems to be the difference in the density behaviour of a melted mixture of different composition at the same temperature. While the melting temperature of pure dolomite is 2 670 K and of quartz sand 2 000 K [4], the melting temperature of dolomite and quartz sand mixture is in range 1 250–2 400 K.

While the temperature of the plasma flow entering the reactor is about 3 500 K and decreases along the length of the reactor, the difference between the entering and the leaving

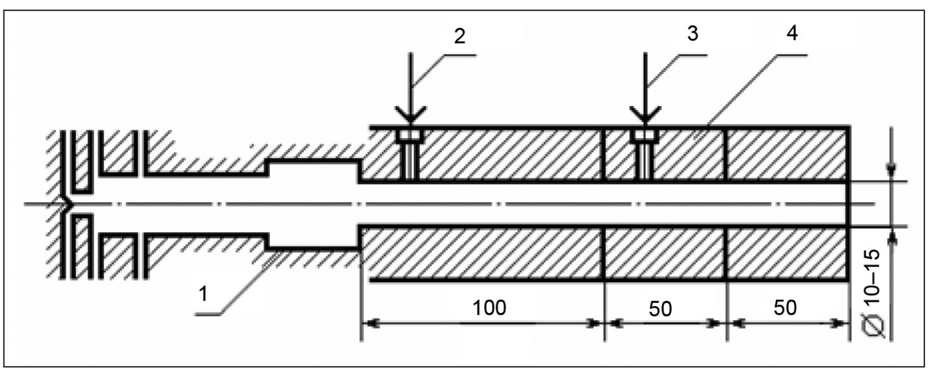


**Fig. 1.** Schematic presentation of uniflow plasmachemical reactor: *1* – plasma torch, *2* – injection place of raw material, *3* – additional gas feeding, *4* – transformable reactor sections

Table 1. **Composition of experimental feeds and plasma jet reactor regimes**

| Dolomite, % | Quartz sand, % | PT power, kW | Air flow rate, g/s | Propane-butane flow rate, g/s | Exhaust gas temperature, K | Flow velocity, m/s |
|---|---|---|---|---|---|---|
| 25 | 75 | 66.2 | 23.245 | 0.985 | 2 316 | 507 |
| 30 | 70 | 68.5 | 22.726 | 1.049 | 2 454 | 522 |
| 35 | 65 | 67.9 | 22.608 | 1.151 | 2 516 | 533 |

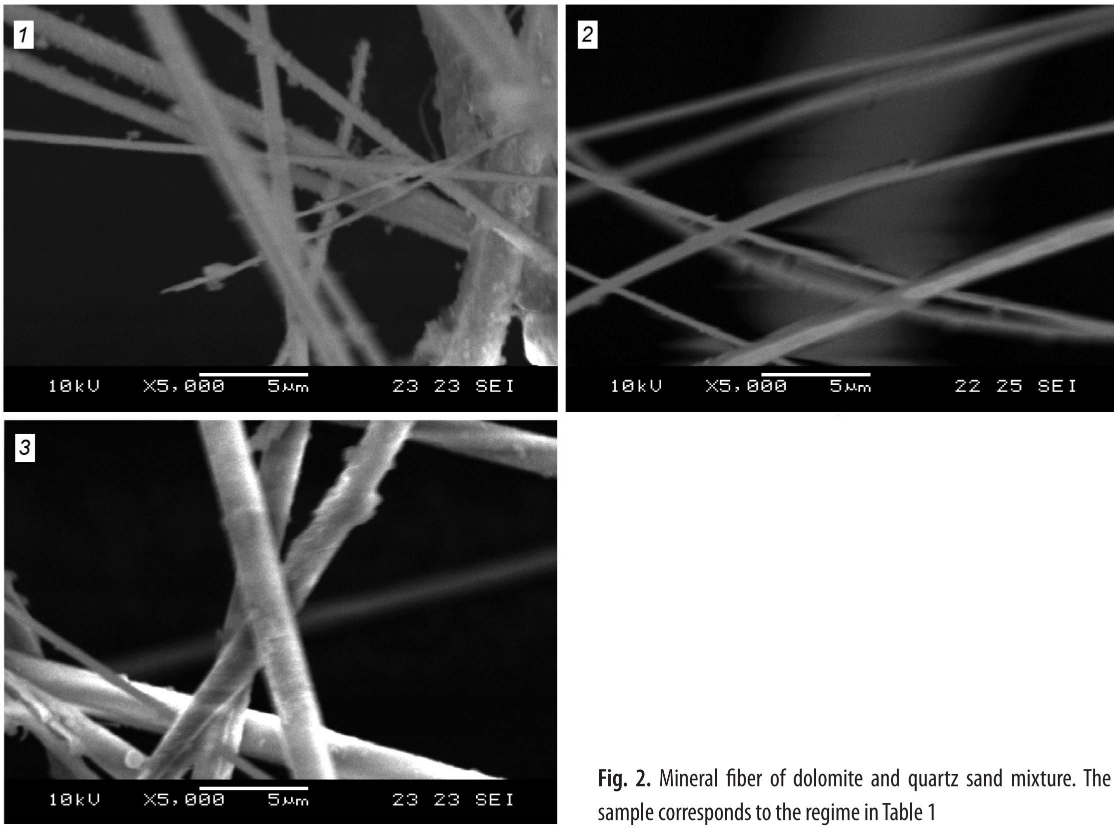


**Fig. 2.** Mineral fiber of dolomite and quartz sand mixture. The number of sample corresponds to the regime in Table 1

flow temperatures is about 1 000 K. This temperature drop is influenced by heat transfer among the dispersed particles, plasma flow and reactor walls. When particles of the dolomite and quartz sand mixture enter the reactor, the temperature of the flow is sufficient for melting all of these particles. When the melt flow comes to the outlet of the reactor, the temperature of the flow decreases, so its viscosity increases. The best conditions for fiber production are achieved when the melt viscosity is about 5 Pas [5]. The viscosity of the mixture containing 35% of dolomite is higher than that of the mixture containing 25% of dolomite because the melting temperature of dolomite is higher than that of quartz. So, it influences the quality of produced fiber.

A mixture of 60% of quartz sand and 40% of dolomite was used with two different designs of the plasma-chemical reactor (Fig. 1). Two outlet exhausts with different diameters (0.010 m and 0.015 m) were used to determine the impact of the velocity of the flow-leaving the reactor on the quality of the obtained mineral fiber. In Table 2, the basic parameters of the plasma-chemical reactor are presented.

In Table 2 one can see that, at the same plasma-chemical reactor basic parameters, decreasing the outlet exhaust diameter from 0.015 m to 0.010 m determines the increase of the plasma flow velocity leaving the reactor about 2.3 times (from 794 m/s to 1 759 m/s). When the outlet exhaust diameter is 0.010 m, the flow velocity exceeds the velocity of sound in the system.

The dispersed particles start mixing with turbulent plasma flow when they enter the reactor. The smallest particles sublimate or evaporate immediately because the flow tempe-

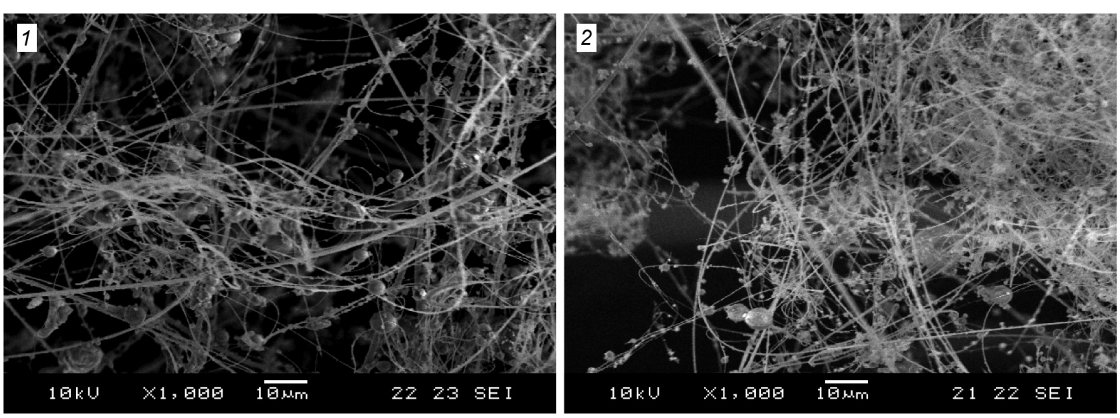


**Fig. 3.** Mineral fibers obtained with different outlet exhaust diameters: *1* – 0.015 m, *2* – 0.010 m

Table 2. **Basic parameters of plasma-chemical reactor**

| Diameter of outlet exhaust, m | PT power, kW | Air flow rate, g/s | Propane-butane flow rate, g/s | Exhaust gas temperature, K | Flow velocity, m/s | Speed of sound, m/s |
|---|---|---|---|---|---|---|
| 0.015 | 68.1 | 16.668 | 0.732 | 2970 | 794 | 1 092.3 |
| 0.010 | 65.9 | 16.891 | 0.746 | 2903 | 1 759 | 1 080.1 |

rature is very high. Bigger particles stick to the reactor walls and flow out of the reactor as a melt. Plasma flow kinetic energy drags little drops out of the melt, stretches them and forms a fiber. Figure 3 shows that when the velocity of plasma flow is higher (Fig. 3.2), the obtained fibers and granules are smaller in diameter. It is so because the particles melted in the reactor are affected by the bigger kinetic energy and are more stretched. The biggest particles do not melt completely and go out of the reactor as granules. Figure 4 shows the pictures obtained with the Redlake MotionPro X4 high speed camera during the experiment with the regime No. 2 (Table 1).

In the marked place (Fig. 4a), a stream of hot melt appears. The viscosity of the melt is high enough for drawing filaments. However, part of the melted stream chills and solidifies, especially near the cold wall zone and on the border with the plasma jet. The other part of the stream is heated by the plasma flow and keeps its temperature higher than

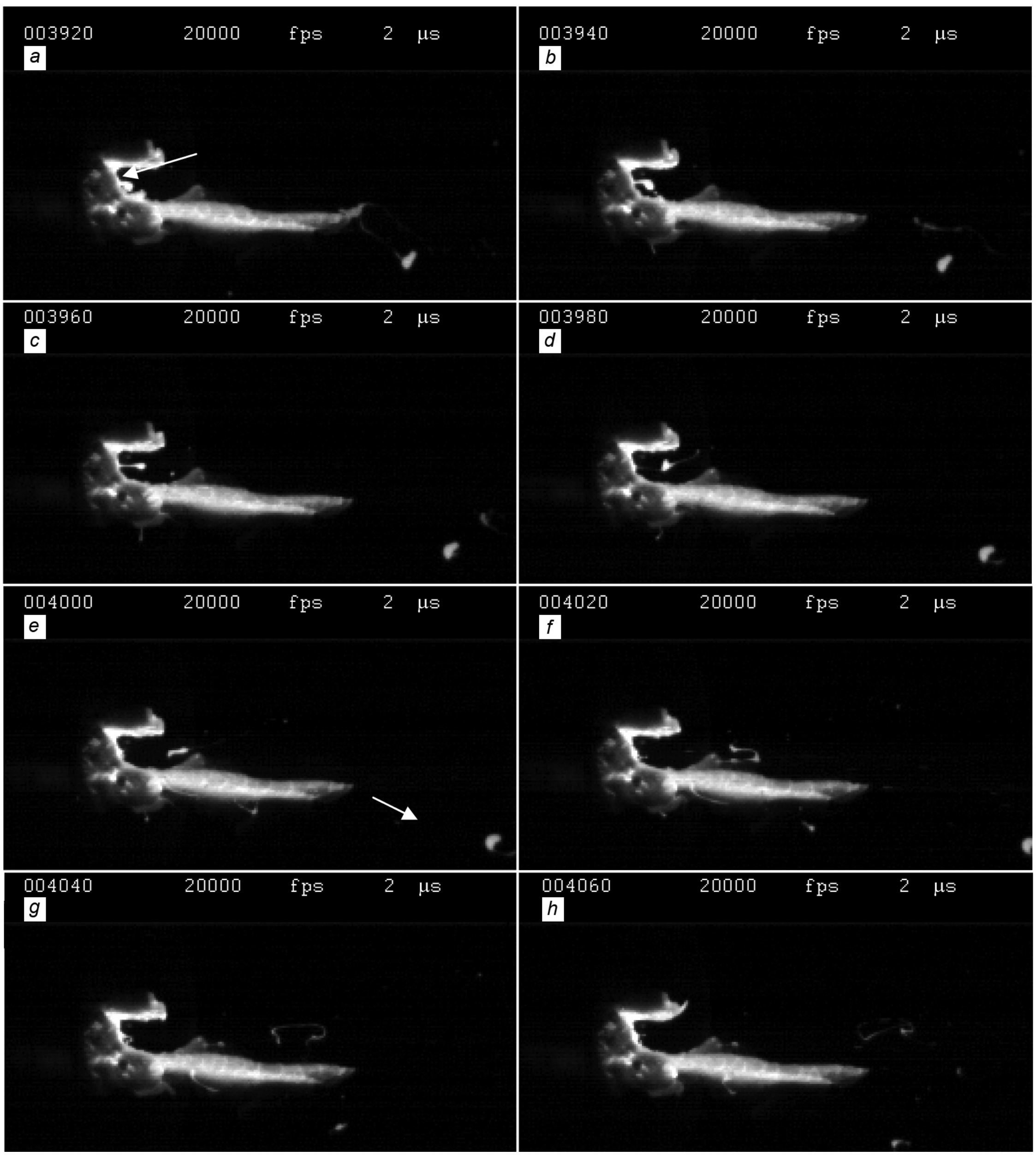


**Fig. 4.** The behaviour of a single fiber filament captured by a high speed camera

the melting temperature. This stream is increasing in volume because the velocity of the melted substance leaving the reactor decreases. Therefore, there appear partly melted structures with the volume and mass increasing during the soldering process. They don't solidify completely because the temperature of the melt is high enough. For this reason, certain partly melted small pieces may separate and get blown out of the vents at any moment. Then the kinetic energy of the plasma flow drives the melted domain and drags a fiber filament.

The time of forming a single filament of fiber is possible to estimate from Fig. 4. It depends mainly on the size of the partly solidified domain, viscosity and gas flow velocity. In the presented case, the time required for the formation of fiber is in the order of 7 ms.

White spots in the segments of Fig. 4 (marked in Fig. 4e) are not fully melted particles and particles separated from the main layer and turned into granules. These granules move with a high velocity (~520 m/s), cool off and pollute the fiber collected on the mesh by sticking to it. To prevent this pollution, the method of redirection of the fiber and granules to different sides must be employed. It has been found that granules separated from the fiber became hollow; therefore, they could be used as high temperature material for specific applications [6].

## 4. CONCLUSIONS

1. Dolomite content in mixtures with quartz sand influences the shape and size of fiber filaments. The average diameter of produced fiber filaments increases with increasing dolomite content in the mixtures.

2. The outlet exhaust diameter of the plasma-chemical reactor influences the quality of the obtained fiber filaments. As the outlet diameter decreases, the average diameter of fiber and granules also decreases.

3. There exists a possibility to form fibers by employing kinetic energy of the plasma flow. It drives the melted domains and drags fiber filaments.

4. The duration of the formation of a single fiber filament depends on the size of a separated domain, the viscosity of the mixture and on the gas flow velocity. In the presented case, the time of prompt fiber filament formation is about 7 ms.

## ACKNOWLEDGEMENTS

The authors acknowledge the Agency for International Science and Technology Development Programmes in Lithuania for financial support.

Received 20 January 2010
Accepted 26 May 2010

## References

1. Hocevar M., Sirok B., Blagojevic B. Mineral wool production monitoring using neural networks. *International Journal of Information Technology.* 2005. Vol. 11. Issue 9. P. 64–72.
2. Valinčius V., Kėželis R., Valatkevičius P., Milieška M. Melting and conversion into fibre dolomite and quartz sand mixtures by means of plasma spraying. *Proceedings of 10th International Conference on "Gas discharge plasmas and their technological applications".* Tomsk, Russia, 2007. P. 441–444.
3. Milieška M., Kėželis R., Kalpokaitė-Dičkuvienė R., Čėsnienė J., Brinkienė K., Mėčius V. Plazminio metodo taikymas formuojant nanoplaušą iš naftos produktų gamybos proceso atliekų (ceolitų). *Energetika.* 2008. T. 54. Nr. 4. P. 54–58.
4. Milieška M., Valinčius V., Kėželis R. Synthesis of high temperature mineral fiber in atmospheric pressure plasma jet. *Proceedings of Annual Conference of Young Scientists on Energy Issues "CYSENI 2008".* Kaunas: LEI, 2008. P. 16–22.
5. Strazdas K., Eidukevičius P. *Mineralinis ir stiklo pluoštas.* Vilnius: Mokslas, 1985. 19 p.
6. Kėželis R., Mėčius V., Pranevičius L. Aliuminio oksido plaušo sintezė plazminiu metodu. *Energetika.* 2003. Nr. 1. P. 46–50.

**Mindaugas Milieška, Romualdas Kėželis, Vitas Valinčius, Vladas Mėčius**

## NEORGANINIŲ METALŲ OKSIDŲ PLAZMINIO LYDYMO IR PLUOŠTINIMO PROCESO REALIZACIJA IR ANALIZĖ

*Santrauka*

Straipsnyje pateikta nauja plazminė technologija pluošto gamybai iš neorganinių metalų oksidų, pranašesnė už tradicines technologijas paprastumu ir gaunamo produkto kokybe. Aprašomas tiesiasrovis plazmacheminis reaktorius, skirtas keraminėms medžiagoms lydyti ir pluoštinti, pateikiamos jo optimalaus darbo sąlygos atmosferos slėgyje ir galutinio produkto, gauto plazminiu pluoštinimu, analizė.

Oras buvo naudojamas kaip plazmą formuojančios dujos ir propanas–butanas – papildomos dujos. Plazmos generatoriaus galia buvo 65–69 kW. Mineralinis pluoštas buvo gaunamas iš įvairių dolomito ir kvarcinio smėlio mišinių. Dolomito kiekis mišiniuose kito nuo 25 iki 35 %, kai eksperimento tikslas buvo sužinoti dolomito kiekio mišiniuose įtaką gauto mineralinio pluošto kokybei. Reaktorių paliekančių dujų temperatūra ir greitis buvo atitinkamai 2 316–2 516 K ir 500–530 m/s. Kitu atveju, 60 % kvarcinio smėlio ir 40 % dolomito mišinys buvo naudojamas su dviem skirtingo dizaino plazmocheminiais reaktoriais, kad būtų nustatyta ištekančio iš reaktoriaus srauto greičio įtaka gauto mineralinio pluošto kokybei. Srauto temperatūra buvo 2 900–2 970 K, o srauto greitis – 794–1 759 m/s.

Mineralinio pluošto struktūra ir morfologija nagrinėta skenuojančiu elektroniniu mikroskopu. Pluošto plaukelio suformavimo procesas buvo analizuojamas naudojant greitaeigę kamerą.

Pluošto plaukeliai formuojami pasitelkus srauto kinetinę energiją. Pluošto formavimosi mechanizmas darbe paaiškintas. Plazminio pluoštinimo procese gaunamas mineralinis pluoštas yra atsparus aukštai temperatūrai (iki 1 300 °C), pluošto plaukelio skersmuo ne didesnis kaip 2–5 μm. Toks pluoštas tinka aukštos temperatūros ar triukšmo izoliatorių, katalizatorių ar filtrų gamybai.

**Raktažodžiai:** plazma, plazmacheminis reaktorius, mineralinis pluoštas

**Миндаугас Милешка, Ромуалдас Кежялис, Витас Валинчюс, Владас Мечюс**

## АНАЛИЗ И РЕАЛИЗАЦИЯ ПРОЦЕССА ПЛАЗМЕННОГО ПЛАВЛЕНИЯ И ФИБРИЛЛЯЦИИ НЕОРГАНИЧЕСКИХ ОКСИДНЫХ МЕТАЛЛОВ

*Резюме*

Представленная в данной работе новая плазменная технология по производству волокон из неорганических оксидных металлов опережает традиционные технологии благодаря простоте обработки и качеству полученных продуктов. Представлены описание прямоточного плазмохимического реактора, предназначенного для плавления и фибрилляции керамических материалов, анализ оптимальных условий его эксплуатации при атмосферном давлении и характеристики конечного продукта, полученного в ходе реализации процесса плазменной фибрилляции.

Воздух используется в качестве плазмообразующего газа и пропан–бутан для повышения мощности струи. Мощность плазменного факела в диапазоне 65–70 кВт. Минеральное волокно было изготовлено из различных смесей доломита и кварцевого песка. Количество доломита в смеси варьировало от 25 до 35 %. Целью эксперимента явилось выяснение влияния количества доломита в смеси на качество полученного минерального волокна. Температура и скорость газа выходящей из реактора струи газа – 2 316–2 516 К и 500–530 м/с, соответственно. Затем смесь, состоящая из 60 % кварцевого песка и 40 % доломита, использовалась в двух разных схемах плазмохимического реактора, чтобы определить влияние скорости выходящего из реактора потока на качество полученного минерального волокна. Температура потока составляла 2 900–2 970 К, а скорость течения – 794–1 759 м/с.

Структура и морфология минерального волокна анализировались с помощью сканирующего электронного микроскопа. Процесс волокнообразования был проанализирован с помощью визуализации высокоскоростной камерой.

Волокна были сформированы на основе кинетической энергии потока. Механизм волокнообразования объяснен. Минеральное волокно производимое с использованием плазменного процесса фибрилляции, устойчиво при высокой температуре (до 1 300 °C), диаметр волокна не превышает 2–5 мкм. Он подходит для производства высокотемпературных или шум уменьшающих изоляторов, катализаторов или фильтров.

**Ключевые слова:** плазма, плазмохимический реактор, минеральное волокно