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Development of active catalysts for low Pt loading cathodes of PEMFC by surface tailoring of nanocarbon materials

Z.R. Ismagilov [a,*], M.A. Kerzhentsev [a], N.V. Shikina [a], A.S. Lisitsyn [a], L.B. Okhlopkova [a], Ch.N. Barnakov [b], Masao Sakashita [c], Takashi Iijima [d], Kenichiro Tadokoro [d]

[a] *Boreskov Institute of Catalysis, Prospekt Akademika Lavrentieva 5, Novosibirsk 630090, Russia*
[b] *Institute of Coal and Coal Chemistry, Kemerovo 650616, Russia*
[c] *JATIS, Sogo-kojimachi No. 3 Building, 1-6 Kojimachi, Chiyoda-ku, Tokyo 102-0086, Japan*
[d] *Nippon Steel Corporation, 20-1 Shintomi, Futtsu, Chiba 293-8511, Japan*

Abstract

The use of novel nanocarbon supports—carbon nanofibers (CNF) and amorphous supermicroporous carbons (ASC) for synthesis of platinum cathode catalysts for proton exchange membrane fuel cells (PEMFC) was investigated. Different types of CNF—with "parallel" and "deck of cards" arrangement of graphitic planes and samples of ASC originating from different organic precursors were synthesized and characterized by XRD, electron microscopy and adsorption methods. Platinum catalysts for PEMFC cathodes on different structural types of CNF and one sample of ASC were synthesized and characterized by XRD, electron microscopy, CO adsorption and by studying characteristics of conventional membrane electrode assembly (MEA) cell with a low Pt loading level of 0.02–0.09 mg/cm^2. The MEA testing showed that the Pt cathode catalysts on CNF exhibit inferior performance in comparison with a catalyst on conventional carbon black support Pt/Vulcan XC-72R. The cathode catalyst prepared on ASC support exhibits considerably better output in MEA, compared with Pt/Vulcan XC-72R even at a lower Pt loading.

Keywords: Nanocarbon; PEMFC; Carbon nanofiber; CNF; Cathode; Catalyst; Platinum; Low loading; Supermicroporous carbon

1. Introduction

To achieve uniform and highly dispersed Pt loadings, the proton exchange membrane fuel cell (PEMFC) cathode catalysts are usually supported on carbon supports with a high surface area—over 75 m^2/g. Common supports are carbon blacks with a high degree of graphitic character: Vulcan XC-72R, Black Pearls BP 2000, Ketjen Black, etc. The support material must provide a high electric conductivity and high and uniform catalyst dispersion, give good reactant gas access to the catalyst and have good corrosion resistance. On the whole, the conventional carbon black supports satisfy these requirements [1].

Recent publications show that, in order to increase the efficiency of cathode catalysts, novel non-conventional materials are proposed as supports for Pt. The examples are supports produced from aerogel nanocarbon [2], nanofibers of organic pigments [3], carbonized micro-cellular polymer materials [4].

The use of novel supports allow increase of catalyst activity, decrease of electrode thickness and reduction of Pt content in cathode to values of ca. 0.1 mg/cm^2, thus increasing the electrode efficiency and minimizing its cost.

The cost-effective use of PEMFC is possible if the content of Pt in PEMFC, primarily in cathode, is substantially reduced. The target is to achieve Pt loading in cathode 0.02 mg/cm^2.

The Pt content in cathode can be reduced by increasing the catalyst activity, which can be accomplished by surface tailoring of carbon support material resulting in high and uniform concentration of supported Pt particles with a size of 2–3 nm, preferably ca. 2 nm. Using such active cathode catalysts, smaller thickness of cathode can be attained. Thus,

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* Corresponding author. Tel.: +7 3832 341219; fax: +7 3832 397352.
E-mail address: ZRI@catalysis.nsk.su (Z.R. Ismagilov).

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the approach for preparation of low Pt loading cathodes consists in the use of active catalysts on new carbon supports, so that the electrocatalyst layer can be made very thin—ca. 1 μm and the Pt content per electrode area can be decreased by an order of magnitude to values 0.02–0.05 mg/cm^2. The decrease of the electrode thickness is beneficial also because it increases fuel cell efficiency by easier oxygen diffusion into the electrode and easier water removal.

The dispersion of platinum, catalytic activity and efficiency of platinum electrocatalysts presumably depends on the structure of the carbon support. Conventional supports—carbon blacks have predominantly basal graphite planes on their surface, resulting in weak interaction with supported platinum. This leads to the formation of relatively large globular platinum particles, subject to sintering (increase in particle size). We propose to use carbon nanofibers (CNF) as supports for platinum cathode catalysts, because these materials have different structure—namely, regular arrangement of graphite planes with their edges forming the outer surface of the fibers. These edges may serve as suitable sites for the stabilization of small platinum particles. In addition regular arrangement of such sites can provide more uniform distribution of platinum particles on the surface.

During the past decades, CNF have attracted ever-increasing interest of scientists and technologists. The family of CNF encompasses novel materials produced by the decomposition of hydrocarbons over 3d-metal catalysts [5–16]. Catalytically grown CNF was the subject of numerous studies (see, for example, the works by Baker and co-workers [5–7], Rosrtup-Nielsen and co-workers [8,9], Geus and co-workers [10–13] and our publications [14–17]) due to its unique structure and properties. This kind of carbon is suggested to be used for the structural reinforcement applications [18], adsorbent [19] and as a catalyst support [20–27].

The use of CNF as catalyst support in comparison with conventional supports (activated carbon, alumina) was shown to result in an increase of activity and selectivity of the catalysts in hydrogenation reactions [21–27]. The more detailed study of the performance of Ni catalysts supported on CNF of different structures in hydrogenation of alkenes and dienes showed that the catalyst activity and selectivity are extremely sensitive to the support structure [27].

Thus, the attraction of CNFs follows from possibility of purposeful synthesis and peculiarities of their structure. Three types of CNF different by structure are well known: with graphene planes arranged perpendicular to the filament axis (deck of cards morphology), at an angle of 45° to the axis (herringbone morphology) or parallel to the axis, forming multi-wall nanotubes (Fig. 1).

Various carbon-containing gases (CH_4, C_2H_4, C_2H_2, CO) can be used as feedstock for the production of CNF, while metals of the iron subgroup and their alloys are traditionally used as the catalysts for hydrocarbon decomposition.

Another type of nanocarbon materials different from carbon blacks—amorphous supermicroporous carbon (ASC) [28] is an attractive material for cathode catalyst support because it has a very high specific surface area—up to 3300 m^2/g and large specific volume of micropores (i.e. pores with a diameter less that 2 nm)—from 1 to 1.6 cm^3/g. These micropores can contribute to stabilization of small Pt particles.

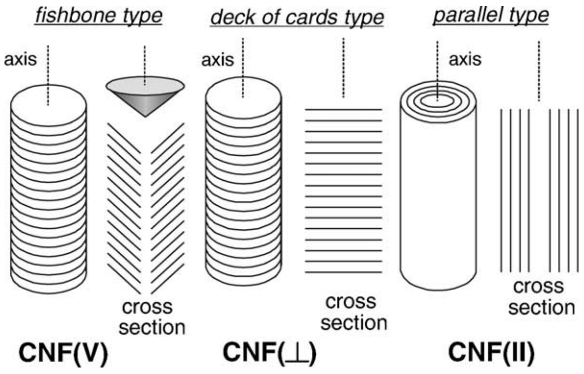

Fig. 1. Schematic representation of three types of CNF [13].

Thus, in this paper, we present data on synthesis of prospective catalysts for cathodes of PEM fuel cells on novel carbon materials: CNF and ASC, their characterization and MEA performance results.

2. Experimental

2.1. Synthesis of CNF

Decomposition of methane to produce CNF was carried out in a vibro-fluidized bed reactor that makes it possible to conduct the reaction under isoconcentration and isothermal conditions, prevent agglomeration of the carbonized catalyst and synthesize uniformly structured CNF [14–17]. The catalyst (~0.1 g) was placed into the reactor (~30 cm^3 in volume), the methane was supplied and the reactor was heated up to the required temperature—625 °C. Undiluted methane ($p = 1$ bar, 99.99% purity) was supplied into reactor at the rate of 45–90 l/(h g catalyst). Concentration of methane was measured by gas chromatography, and methane conversion was calculated. Carbon deposition was measured by weighting the samples after reaction, which was performed until complete catalyst deactivation. The catalysts 62% Fe–8% Ni–30% Al_2O_3 and 62% Fe–8% Ni–30% Al_2O_3 were used for growing CNF(||) and the catalysts 65% Ni–25% Cu–10% Al_2O_3 for preparation of CNF(⊥) [14–17].

2.2. Synthesis of ASC

Supermicroporous amorphous carbons were synthesized by mixing an organic precursor: oil coke, hydroquinone, etc. with concentrated sulfuric acid and potassium (or sodium) nitrites followed by thermal treatment at 700–800 °C in a reductive or inert medium.

The typical synthetic procedure is performed as follows. The initial carbonaceous precursor is ground to particle size 0.1–0.2 mm. A 5.5 g of the ground material is mixed with 90 ml of concentrated sulfuric acid under stirring and cooling with ice. Sodium nitrite in amount 36 mol/kg of the precursor (13.5 g) is added to the mixture gradually under stirring and the mixture is heated until foam formation and evolution of nitrogen oxides stop. Then, the mixture is diluted by water and evaporated to one-third of its initial volume. After cooling the precipitate is separated and washed to attain neutral pH of washing water. The product obtained is mixed with concentrated solution of 23 g of sodium hydroxide (107 mol/kg precursor). The mixture is heated to evaporate water and form a melt. After the end of the gas evolution, the melt is subjected to carbonization at 700 °C for 10 min. The obtained material is washed with water, then with 0.5 M H_2SO_4, then again with water until neutral medium. The washed product is dried at 105–115 °C. The typical yields of the obtained supermicroporous carbons are 20–30%.

2.3. Preparation of Pt cathode catalysts

For catalysts preparation, H_2PtCl_6 was used as the starting Pt compound, with following alkaline hydrolysis and Pt reduction.

The catalyst preparation procedure includes the following stages:

- Acid washing of the support from particles of metals—catalysts for CNF synthesis.
- Support drying.
- Preparation of solutions.
- Preparation of aqueous suspension of CNF.
- Adsorption of Pt precursor via alkaline hydrolysis.
- Pt reduction.
- Spectrophotometric control for completeness of the Pt deposition.
- Filtration and washing of the precipitate from Cl^- ions.
- Drying.

The catalyst preparation was made with variation of the Pt loading on the support (5, 10 and 30 wt.% of Pt in the final samples), alkaline agent (NaOH or Na_2CO_3), reducer (sodium formate or hydrogen), and other conditions (duration of the adsorption of H_2PtCl_6, temperature and duration of the hydrolysis and reduction, etc.). The CNF supports used for preparation of catalysts to be further tested in MEA were ground and jet-milled to size of 30–40 nm. The support ASC-1 was prepared following special procedure to produce particles of required size. Vulcan XC-72R was purchased from Cabot Corp. It had particle size 30 nm, BET area 254 m^2/g.

2.4. Characterization of carbon supports and cathode catalysts

Samples of carbon supports were investigated by XRD, TEM, HRTEM and adsorption methods. The catalysts were investigated by XRD, TEM and HRTEM. Pt dispersion was measured by XRD and CO adsorption method.

The XRD studies were performed in a HZG-4 diffractometer using Cu Kα radiation. Crystallite sizes were calculated from the line width following the Scherrer equation, TEM pictures were obtained in a JEM-100 CX. Studies by high-resolution electron microscopy were performed with HRTEM JOEL 2010, magnification up to 3,116,000×. The adsorption measurements were carried out using an ASAP-2400 to provide adsorption of N_2 at 77 K.Metal dispersion was probed by express method with CO chemisorption in a conventional flow system with a thermal conductivity detector and hydrogen as a support gas. Assuming CO adsorption on surface Pt in proportion one molecule per atom, the Pt dispersion was calculated by the formula: $D = CO_{ads}$ (moles)/Pt (moles). The average particle size was estimated using the formula: d (nm) = 1.08/D [29].

2.5. Preparation of membrane electrode assemblies and MEA operating conditions

Cathodes of membrane electrode assemblies were prepared by spraying a slurry consisting of the catalyst (30% Pt on carbon support), Nafion solution, hydrophobic powders, water and ethanol onto a Nafion-112 membrane of 50 μm thickness with effective cross-section of 25 mm × 25 mm and subsequent removing of solvents by heating to 150 °C. The content of Pt in cathode between about 0.02 and 0.09 mg/cm^2 was varied by amount of slurry loading. The anode in the MEA tests was a conventional 30 wt.%

Table 1
XRD characterization of CFC samples

Sample	T (°C)	d_{002} (nm)	L_c (nm)	L_a (nm)
CNF(⊥)	625	0.341	5.2	9.5
CNF(||)	625	0.342	5.5	8.5

Table 2
Textural characteristics of CNF samples

Sample	BET surface (A_{BET}, m^2/g)	Mesopore surface (A_{ME}, m^2/g)	Micropore volume (V_μ, cm^3/g)	Total pore volume (V_S, cm^3/g)	Average pore diameter (D^{BET}, nm)
CNF(⊥)	260	231.2	0.014	0.400	6.2
CNF(||)	150	112.4	0.01	0.406	17.5

Table 3
Textural characteristics of ASC samples

No.	Type ASC	Precursor	A_{BET} (m^2/g)	A_{ME} (m^2/g)	V_S (cm^3/g)	V_μ (cm^3/g)
1	ASC-1	Oil coke	3331.0	182.0	1.84	1.56
2	Ph	Phenol	2240.1	369.0	1.53	0.98
3	OQ	Oxyquinoline	2548.2	313.3	1.59	1.21
4	HQ	Hydroquinone	2453.2	111.3	1.36	1.22
5	ONA1K	*o*-Nitroaniline K^+	1673.7	55.9	0.87	0.79
6	ONA2K	*o*-Nitroacetonilide K^+	1691.8	30.7	0.85	0.80
7	ONA1	*o*-Nitroaniline Na^+	1920.6	242.0	1.34	1.05
8	ONA2	*o*-Nitroaniline Na^+	2559.0	392.3	1.74	1.25
9	ONA3	*o*-Nitroaniline Na^+	2508.0	156.7	1.51	1.31
10	HQ1	Hydroquinone K^+	2697.4	104.6	1.50	1.38
11	HQ2	Hydroquinone K^+	2835.0	171.9	1.70	1.50
12	HQ3	Hydroquinone K^+	2764.8	172.0	1.64	1.43
13	DNPh	2,4-Dinitrophenol	632.4	55.8	0.36	0.26
14	DNA	2,4-Dinitroaniline	1148.3	24.8	0.57	0.52
15	BA	Barbituric acid Na^+	500.0	81.0	0.38	0.19
16	BA	Barbituric acid K^+	1400.0	610.0	1.47	0.41
17	BQDO1	*n*-Quinondioxime:*n*-hydroquinone (1:2)	2470.0	304.0	1.64	1.27
18	BQDO2	*n*-Quinondioxime:*n*-hydroquinone (1:2)	2620.0	824.0	2.14	1.07
19	BQDO3	*n*-Quinondioxime:*n*-hydroquinone (1:2)	2770.0	499.0	1.92	1.29
20	QE-10	Quinolic ether	2360.0	95.0	1.25	1.10

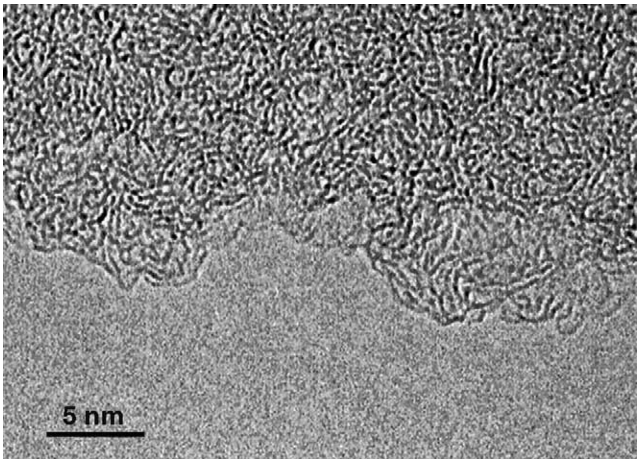

Fig. 2. HRTEM image of ASC-1 sample prepared from oil coke.

Pt/Ketjen Black of 0.05 mg Pt/cm^2 in all measurements. A hydrophobic porous carbon paper (Electrochem Inc. EC-TP1) serving as a gas distributor and current collector was applied to the electrodes. The MEAs were assembled in a standard graphite cell frame. The tests were performed under the following conditions: cell temperature 80 °C, pressures of H_2 of relative humidity of 100% at 85 °C and O_2 of relative humidity 100% at 75 °C were 0.1 MPa.

3. Results and discussion

3.1. Characterization of CNF and ASC

The XRD patterns of the CNF samples are only different in the widths and positions of (0 0 *l*)-type reflections, i.e.

Table 4
Metal dispersion in the catalysts prepared on CNF

No.	Catalyst code[a]	Catalyst used for CNF preparation	Pt loading (wt.%)	Characterization methods		
				Dispersion CO/Pt (%)	Particle size from CO/Pt (*D*, Å)	XRD
1	5C(⊥)F	65Ni25Cu	5	46	23	Carbon phase; Pt with $D = 23$ Å
2	10C(⊥)F	65Ni25Cu	10	35	31	Carbon phase; Pt with $D = 43$ Å
3	30C(⊥)F	65Ni25Cu	30	20	54	Carbon phase; Pt with $D = 44$ Å
4	5C(||)F	62Fe8Ni	5	34	32	Carbon phase; Pt with $D = 31$ Å
5	10C(⊥)H	65Ni25Cu	10	53	20	Carbon phase; Pt with $D = 21$ Å
5a	10C(⊥)F	65Ni25Cu	10	40	27	Carbon phase; Pt with $D = 29$ Å
6	5C(⊥)H	75Ni15Cu	5	64	17	Carbon phase; Pt with $D = 17$ Å
6a	5C(⊥)F	75Ni15Cu	5	46	23	Carbon phase; Pt with $D = 24$ Å
7	10(⊥)H	75Ni15Cu	10	51	21	Carbon phase; Pt with $D = 21$ Å
7a	10C(⊥)F	75Ni15Cu	10	33	33	Carbon phase; Pt with $D = 25$ Å

[a] In the catalyst code, the first figure designates Pt content in the catalyst, the sign after C refers to CNF structure, index F means Pt reduction by formate, and H refers to Pt reduction by hydrogen.

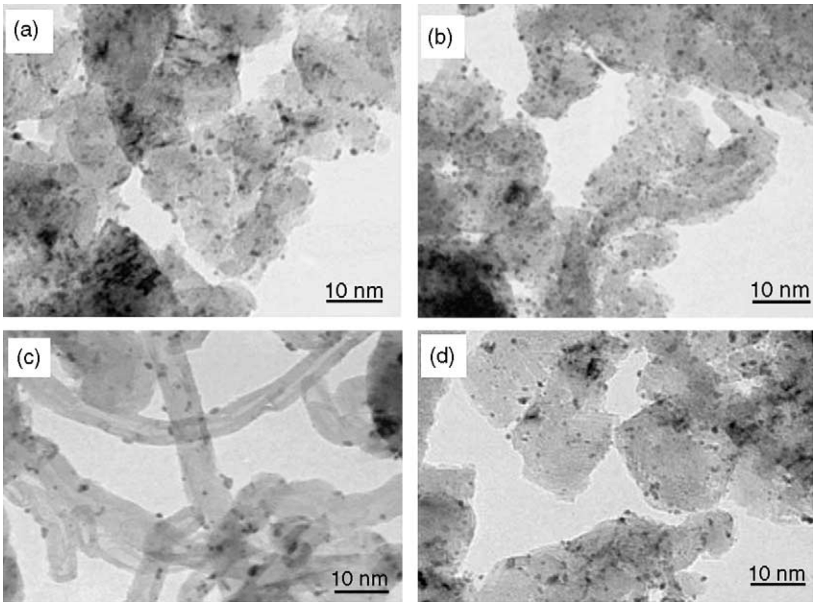

Fig. 3. TEM pictures of Pt catalyst samples: (a) 5C(⊥)F; (b) 10C(⊥)H; (c) 5C(||)F; (d) 10C(⊥)F.

there are only qualitative differences. Interplanar distance d_{002} and average CSD (crystallite) sizes along the *a*- and *c*-axis of carbon (L_a, L_c) are presented in Table 1. The d_{002} ranges between 0.341 and 0.342 nm, that is higher than for ideal graphite (0.335 nm). The average values of L_c and L_a are 5.2–5.5 and 8.5–9.5 nm, respectively.

Thus, XRD characterization indicates that CNF is the typical turbostratic carbon with a high d_{002} and low L_a and L_c values [30], i.e. CNF filaments consist of mutually disoriented domains with the graphite-like structure.

The data on BET surface area, mesopore surface area, micropore volume and total pore volume are summarized in Table 2. BET surface area is over 100 m^2/g. The micropore volume is small in both samples, ~0.01 cm^3/g at the total pore volume of 0.4 cm^3/g. Hence, CNF samples are mesoporous materials with pores of 6–18 nm in average size and a large surface area—over 100 m^2/g.

The preparation of amorphous supermicroporous carbon was performed from various initial precursors. The used precursors and textural properties of the obtained materials are shown in Table 3. These are typical microporous

Table 5
Characteristics of catalysts prepared for MEA test

Catalyst	Pt content (%)	D_{Pt} (nm)	
		XRD	TEM
30% Pt/CNF(⊥)	33.2	4.4	3–5
30% Pt/CNF(||)	31.9	4.1	3–5
30% Pt/ASC-1	30.0	3.2	3–4
30% Pt/XC-72R	36.4	4.7	3–5

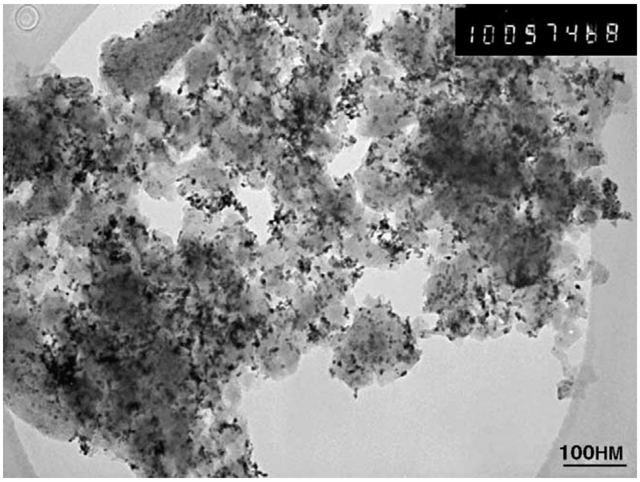

Fig. 4. TEM image of 30% Pt/CNF(⊥).

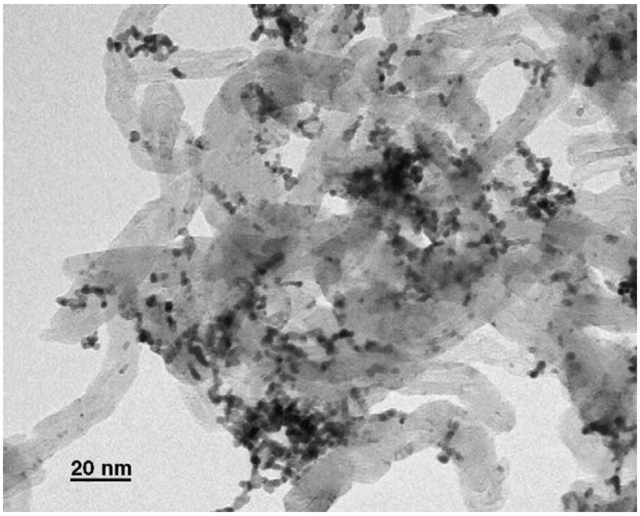

Fig. 5. TEM image of 30% Pt/CNF(||).

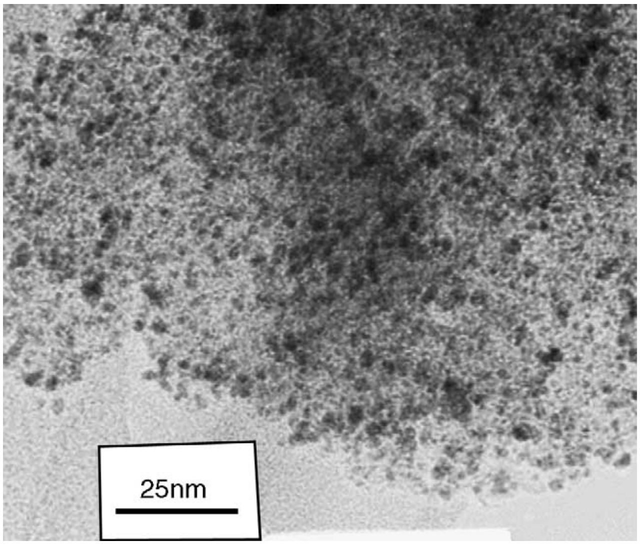

Fig. 6. TEM image of 30% Pt/ASC-1.

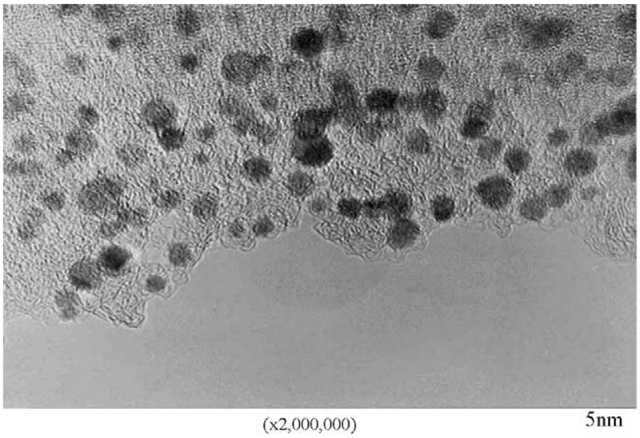

Fig. 7. HRTEM image of 30% Pt/ASC-1.

materials with high surface area exceeding 2000 m^2/g and large volume of micropores—over 1 g/cm^3. The micropore volume is over 80% of the total pore volume, with average pore size close to 2 nm.

The HRTEM studies on the example of ASC-1 formed from oil coke (Fig. 2) show that the material contains fragments with fully disordered cellular structure which are built up by graphite-like layers (graphenes) of monoatomic thickness (ca. 0.3 nm). There are cells of subnanometer characteristic size corresponding to micropores between the bent graphene layers.

Of the samples prepared, the sample ASC-1 was chosen for further studies as a support for Pt cathode catalyst of PEMFC because it has the largest micropore volume and surface area, and secondly it can be produced in a form of small uniform particles—ca. 40 nm, which can be used directly for electrocatalyst preparation without the stages of material grinding and jet-milling.

3.2. Characterization of Pt cathode catalysts

Catalysts supported on the CNF were prepared as described above using one of the basic techniques for

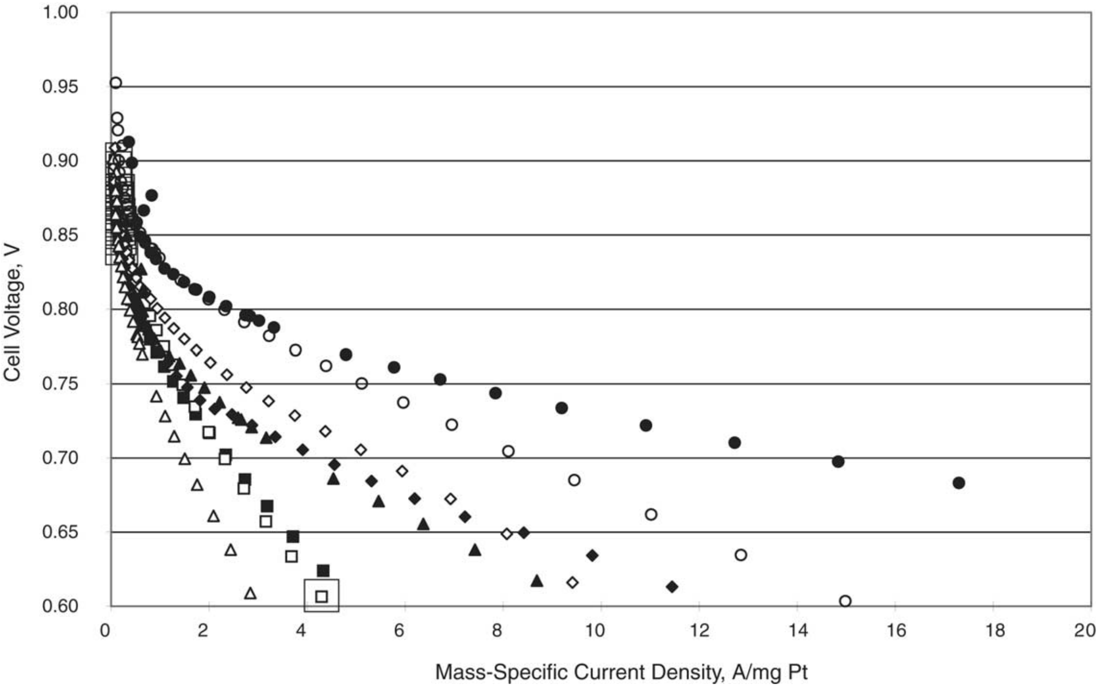

Fig. 8. Voltage vs. mass-specific current density in for MEA with Pt cathodes with low Pt loading and a conventional anode with 30 wt.% Pt/Ketjen Black of 0.05 mg Pt/cm^2. Vulcan XC-72R: (◆) 0.0380 mg Pt/cm^2; (◇) 0.0628 mg Pt/cm^2. Amorphous carbon ASC-1: (●) 0.0175 mg Pt/cm^2; (○) 0.0592 mg Pt/cm^2. CNF(||): (■) 0.0400 mg Pt/cm^2; (□) 0.0639 mg Pt/cm^2. CNF(⊥): (▲) 0.0185 mg Pt/cm^2; (△) 0.0914 mg Pt/cm^2.

preparation of catalysts with noble metals on carbon supports [31]. Several catalysts have been prepared to estimate applicability of this technique to different types of CNF at different Pt loadings on the support.

The used catalyst preparation technique provides rather high dispersion for the supported platinum at a large Pt loading (see data for catalysts 2, 5 and 7 with 10 wt.% of Pt and sample 3 with 30 wt.% of Pt in Table 4) and allow the dispersion to be controlled by variation of the preparation conditions (compare dispersions in the pairs of catalysts 5 and 5a, 6 and 6a, and 7 and 7a, which were prepared on the same support and have the same metal loading). Generally, reduction by hydrogen results in higher Pt dispersion in comparison with liquid phase reduction by formate ion.

There is very good correspondence between average size of Pt particles obtained by CO adsorption measurement and XRD.

The micrographs of some Pt catalysts on CNF of different types are shown in Fig. 3. TEM pictures of Pt on support C(⊥) show pieces of broken filaments (the breaking of filaments took place upon jet-milling) with Pt fine particles supported on carbon. The comparison of the TEM images of the catalysts of the same composition, but prepared by different techniques (10C(⊥)H and 10C(⊥)F) shows that reduction by hydrogen leads to higher dispersion and more uniform Pt distribution as compared to liquid phase reduction by formate ion—in agreement with data obtained by CO adsorption and XRD.

Sample 5C(||)F retains initial carbon structure as multi-wall nanotubes with long unbroken filaments, even after jet-milling of the support, and Pt particles are bonded to the external surface of the filaments. The Pt particles size is close to that of the sample 10C(⊥)F and 5C(⊥)F, but larger than that in the sample 10C(⊥)H.

For MEA tests we used 30% Pt/CNF(⊥) and 30% Pt/CNF(||) and for comparison the catalyst on conventional support 30% Pt/Vulcan XC-72R synthesized by the same method. The catalyst 30% Pt/ASC-1 was synthesized in Nippon Steel Corporation using proprietary technique. The catalyst characteristics are given in the Table 5.

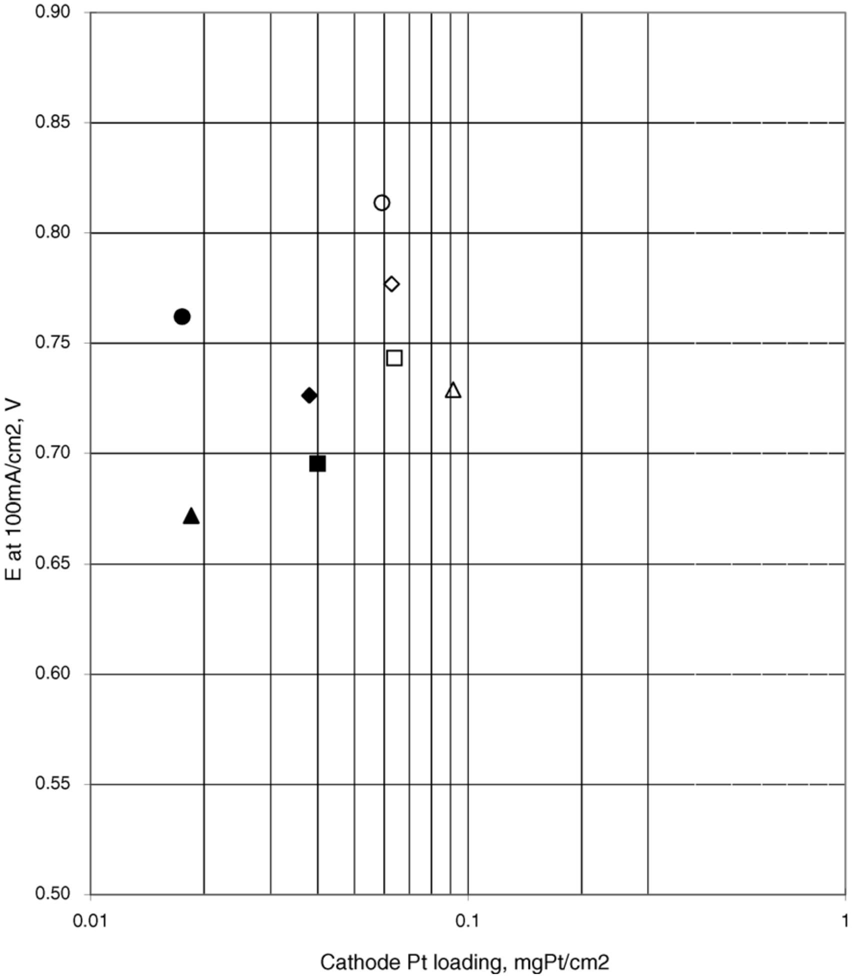

Fig. 9. Voltage at current density of 100 mA/cm^2 of geometric electrode area vs. Pt loading in cathodes for MEAs with low Pt loading cathodes and a conventional anode of 0.05 mg Pt/cm^2 with 30 wt.% Pt/Ketjen Black. Vulcan XC-72R: (◆) 0.0380 mg Pt/cm^2; (◇) 0.0628 mg Pt/cm^2. Amorphous carbon ASC-1: (●) 0.0175 mg Pt/cm^2; (○) 0.0592 mg Pt/cm^2, CNF(||): (■) 0.0400 mg Pt/cm^2; (□) 0.0639 mg Pt/cm^2. CNF(⊥): (▲) 0.0185 mg Pt/cm^2; (△) 0.0914 mg Pt/cm^2.

The micrographs of the catalysts are shown in Figs. 4–7. They demonstrate rather high Pt dispersion. In catalysts 30% Pt/CNF(⊥) and 30% Pt/CNF(||) major part of Pt particles have size of 3–5 nm, some of them are deposited individually and some compose chains or agglomerates consisting of several particles. Electron microscopy studies of 30% Pt/ASC-1 show smaller Pt particles and more uniform Pt distribution in comparison with sample Pt/CNF.

3.3. MEA tests of the catalysts

MEA testing of the Pt cathode catalysts prepared on novel supports were performed in comparison with the catalyst prepared on conventional support Vulcan XC-72R under identical conditions. The results of the tests are shown in Figs. 8 and 9.

Fig. 8 shows the dependence of the voltage of MEAs with different cathode catalysts and different Pt loadings versus mass-specific current density, i.e. current density divided by Pt surface density. It can be seen that the performance of cathodes with Pt/CNF catalysts adjusted to the same Pt loading is inferior to that of the cathodes prepared from the conventional Pt/Vulcan XC-72R catalyst or very close in case of the cathode prepared from Pt/CNF(⊥) with a Pt density of 0.0185 mg Pt/cm^2.

Fig. 9 shows the MEA performance characteristic defined as the MEA output voltage at a constant current density of 100 mA/cm^2, versus Pt loading in the cathode. It can be concluded that the novel catalyst 30% Pt/ASC-1 provides excellent MEA output with the voltage close to 0.8 V at very low platinum loadings 0.0175–0.0592 mg Pt/cm^2, considerably exceeding by the performance the other studied catalysts even at a lower Pt loading.

4. Conclusion

We have shown potential applicability of novel nanocarbon supports—carbon nanofibers and amorphous supermicroporous carbons for synthesis of active platinum cathode catalysts for proton exchange membrane fuel cells. Different types of CNF: with ‘‘parallel’’ and ‘‘deck of cards’’ arrangement of graphitic planes and samples of ASC from different precursors were synthesized and characterized by XRD, electron microscopy and adsorption methods. CNF samples studied are mesoporous materials with pores of 6–18 nm in average size and a large mesoporous surface area—over 100 m^2/g. The synthesized ASC samples are typical microporous materials with very high surface area exceeding 2000 m^2/g and large volume of micropores—over 1 g/cm^3. Platinum catalysts for PEMFC cathodes on different structural types of CNF and one sample of ASC were synthesized and characterized by TEM, XRD and CO adsorption. The used catalyst preparation technique provides rather high dispersion for the supported platinum at a large Pt loading. The catalysts were further characterized by studying characteristics of conventional MEA cell with a low Pt loading level of 0.02–0.09 mg/cm^2. The MEA test showed that the Pt cathode catalysts on CNF exhibit inferior or comparable performance adjusted to the same Pt loading in comparison with a catalyst on conventional carbon black support Pt/Vulcan XC-72R. On the contrary, the cathode catalyst prepared on the ASC-1 support provides excellent MEA output and exhibits better performance compared with the Pt/Vulcan XC-72R and other catalysts even at lower Pt loadings.

Thus, the application of novel supermicroporous materials as supports for catalysts for low Pt loading cathodes appears to be promising. Further research is now in progress on the improvement of Pt dispersion at high loadings on ASC-1, studies of catalysts on ASC supports prepared from different precursors and also on surface treatment of CNF supports for their adaptation as effective carbon supports for cathode catalysts.

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