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Electrochemical Society Interface

vol. 26, iss. 1, Spring 2017, pp. 36-39

ISSN (Print): 1064-8208
ISSN (Online): 1944-8783

DOI: http://dx.doi.org/10.1149/2.F01171if

ECS Classics

Acheson, Silicon Carbide, and the Electric Arc

by Petr Vanýsek

The discovery of an electric arc can be tied to the use of an electrochemical energy source. Sir Humphry Davy described in 1800 an electric discharge using electrochemical cells[1] that produced what we would call a spark, rather than an arc. However, in 1808, using an electrochemical battery containing 2000 plates of copper and zinc, he demonstrated an electric arc 8 cm long. Davy is also credited with naming the phenomenon an arc (Fig. 1). An electric arc was also discovered independently in 1802 by Russian physicist Vasily Petrov, who also proposed various possible applications including arc welding. There was a long gap between the discovery of the electric arc and putting it to use.

Electrochemical cells were not a practical source to supply a sustained high current for an electric arc. A useful application of this low voltage and high current arc discharge became possible only once mechanical generators were constructed. Charles Francis Brush developed a dynamo, an electric generator, in 1878, that was able to supply electricity for his design of arc lights. Those were deployed first in Philadelphia and by 1881 a number of cities had electric arc public lights. Once that happened, the application and new discoveries for the use of the electric arc followed. Electric arc for illumination was certainly in the forefront. First, electric light extended greatly the human activities into the night and second, public street electric lights, attracting masses of spectators, were the source of admiration, inspiration, and no doubt, more invention.

The electric arc became an essential tool leading to a number of discoveries in science and technology and to a number of technological processes. In the anglophone and certainly in the American awareness of the invention of artificial light, it is Edison and the light bulb that come to mind; without doubt the light bulb evokes the notion of the glass envelope of Edison's construction. But the invention of useful artificial electric light precedes Edison's patent of a carbon filament of 1879 by a few years. Before the light bulb, electric arc lighting became quickly popular, but it had many disadvantages. Among these, the most significant was that the graphite rods, as they burned off, became shorter, the distance between them longer, and the arc eventually flamed out. Pavel Yablochkov came up with a design for how to move the rods closer, in an automated fashion, to maintain a constant arc. He received in 1876 a French patent for this self-regulated electric arc lighting design. The high temperature in the arc made it useful for lighting, but made it equally useful for many technical operations as well. Electric arc welding became practical and was demonstrated at the International Exposition of Electricity in Paris in 1881. Heating and melting with an arc was practiced around that time as well. The heat, melting, and simultaneous electrochemistry in the melt led to aluminum preparation by Hall and Heroult, in 1886 and 1888, respectively.[2] Various experiments with electric arc followed, one of which led to the great discovery of Edward Goodrich Acheson, who invented manufacturing of carborundum and patented the process in 1893.

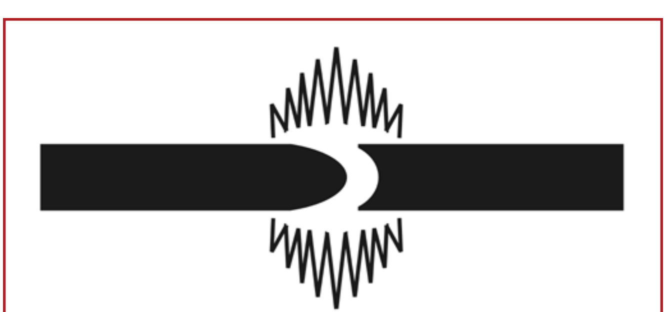

Fig. 1. *Classical diagram of a DC electric arc. During the operation the positive electrode was used up much faster, thus forming a crater on its tip.*

Acheson (Fig. 2) was born March 9, 1856 in Washington, Pennsylvania and was raised in Pennsylvania coal country. He quit school at the age of 16 in order to work and support his family when his father became seriously ill and subsequently died in 1873. Acheson labored on the railroad, but spent his after-work hours studying science and electricity, and conducting his own homemade experiments. One story tells about his practical and profitable electrochemical experiments at this time. He purchased inexpensive yellow-metal pocket watches, used the family silverware forks (made actually from silver at the time) as anodes, and silver-plated the watch cases, which he then sold for a profit. He designed a dynamo and was interested to find employment with some manufacturer of electrical equipment. He approached Edward Weston (of Weston Standard Cell fame) who was manufacturing electroplating dynamos in a shop in Newark, New Jersey, but was turned down for employment. In 1880 Acheson was hired by Thomas Edison as a draftsman and technician at Edison's Menlo Park New Jersey laboratories.

Acheson must have been impressed by the new technology electricity was providing. His involvement with electric arc lighting was first-hand. He learned all the details of electric arc lighting in the preparation for the International Exposition of Electricity in Paris in 1881, the same event where the Yablochkov invention was going to be displayed. After the exposition, Acheson worked for Edison subsidiaries in Europe, where he oversaw the first installations of electric lighting in Belgium, Holland, and Italy. He returned to New York in 1884 and for a year worked as a General Electric electrician for Edison Electric Light Company (1884-85). In 1885 he left Edison and was successful in inventing an anti-induction telephone wire, which he patented and then sold to George Westinghouse for some handsome cash and stock in the Standard Underground Cable Company. Because Westinghouse was Edison's arch-rival, Acheson's relationship with Edison soured. In 1885-86, Acheson worked as a superintendent of the Consolidated Lamp Company of Brooklyn and also worked on his own, with the support of a few financial backers, to design a new style of a dynamo. This effort, however, ended in failure. Acheson was hired to work for the Standard Underground Cable Company for three years (1886-89) where he worked as an

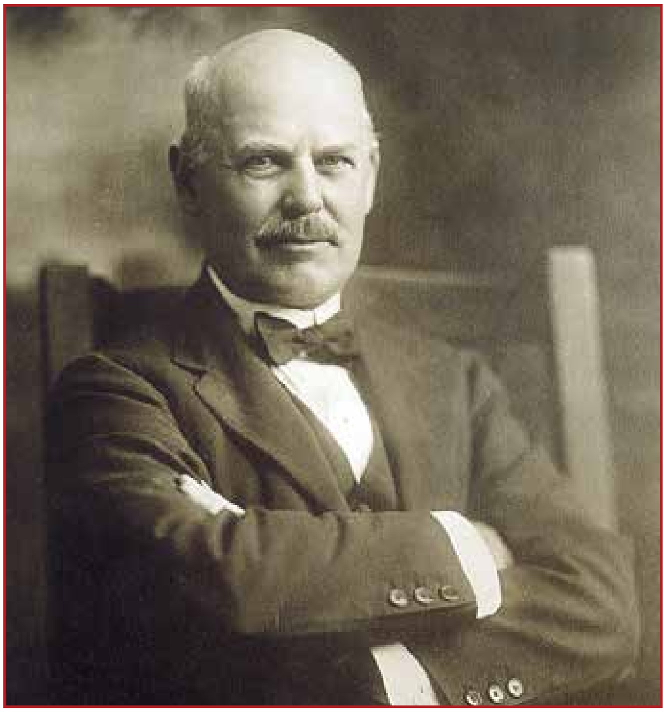

Fig. 2. *Edward Goodrich Acheson.*

electrician, until he decided to establish himself on his own. In partnership he operated a small lighting plant in Monongahela City, Pennsylvania. Its electricity was used for lighting only at night. During the day he was using the dynamo for his experiments.

Acheson made his most famous discovery and invention, silicon carbide (trade name Carborundum), in 1891 using the Monongahela City dynamo. Acheson was by his own words[3] always interested in a method through which carbon could be crystallized (into a diamond modification) to produce abrasive materials. His experimental plan in Monongahela was to cause carbon to be dissolved in melted silicate of alumina, and by cooling the melt to exert high pressure on carbon and cause it to crystallize.

The very first experimental design was a furnace made from an iron bowl lined with carbon serving as one electrode. In the central cavity was placed a mixture of carbon and clay (a silicate), and a rod of carbon was placed in the middle of the mixture as a second electrode. Current was passed through the system and after a period of time the cooled mass was broken apart and examined. A few bright blue crystals, very hard, were found close to the carbon electrodes. A new furnace design involved a refractory brick cavity, 10 × 4 × 4 inches in size, allowing experimentation with electrode placement. The electrical supply apparatus could supply regulated current from 100 to 200 A and potential from 1 to 50 V. This was alternating current, so the effects of the current were not electrochemical but solely temperature-based. Again, upon varying conditions, it was possible to produce larger quantities of the hard material. While it was hard, it was also brittle, thus use of the powder as an abrasive became the prime consideration.

At that time Acheson felt there was a need to name the material. As the material was displaying various colors, sapphire blue to ruby red, it was reminiscent of another mineral, corundum, which can display similar colors. Acheson coined the name carborundum from carbon, the principal component of the mix, and the name of the mineral corundum, knowing that the clay in the mix contained alumina, a structural component of corundum. Soon thereafter he realized that the chemical composition was different. There was little aluminum in the material and shortly the compound was determined to be silicon carbide. Acheson wrote, "The fitness of the name, in the eyes of the chemist, is, in view of the now known composition of the substance, doubtful, while in commerce, although phonetic and of pleasing effect in print, it is, perhaps, a trifle lengthy."[3] Still, the name stuck and is in use to this day.

Acheson founded The Carborundum Company in 1891 to market the material for use in dental products, gem polishing, grinding wheels, knife sharpeners, and whetting stones. In 1897 he patented an improved electrical furnace for firing silicon carbide, leading to the construction of the world's largest industrial furnace at his factory. His discovery of silicon carbide has been called one of the most important discoveries in modern industry, but Acheson was a better chemist and inventor than businessman, and he was fired from the presidency of his Carborundum Company in 1901. The firm has been sold several times since then, and is now part of the Saint-Gobain/Norton Industrial conglomerate.

The world exhibitions or expositions organized in various cities were the premier events to introduce both culture and new technologies to the world. The synthetic silicon carbide, carborundum, was introduced to the world at the Chicago World's Columbian Exposition. The event lasted from May 1 to October 30, 1893. It was notable for quite a few events. Electric lighting generated using the alternating current promoted by Nikola Tesla over Thomas Edison's direct current was used to light the fairground. The first Ferris wheel was installed there in June. The Austrian-Bohemian pencil maker Koh-i-noor brought yellow lacquered pencils to the fair and these were hugely popular, remaining a staple to this day. And the Carborundum Co. displayed its industrial production of cutting wheels, catching the eyes of investors from Austria.

Arnold Weissenberger, an investor from the Austrian investment bank Länderbank, traveleled to Chicago to the exhibit accompanied by a professor from Prague University, Friedrich Steiner. They acquired the carborundum patent rights for Austria-Hungary and for Russia. The International Carborundum Works were established with Wilhelm Kaufmann as a director. Their quick acquisition at the Columbian exhibit allowed the immediate establishment of a plant in Europe—the Austrian Carborundum Company at Benateck, Bohemia, now in the Czech Republic, in a town known now by its Czech name Benátky nad Jizerou (Fig. 3 and 4). Carborundum production there started in 1893 and the availability of grinding stones

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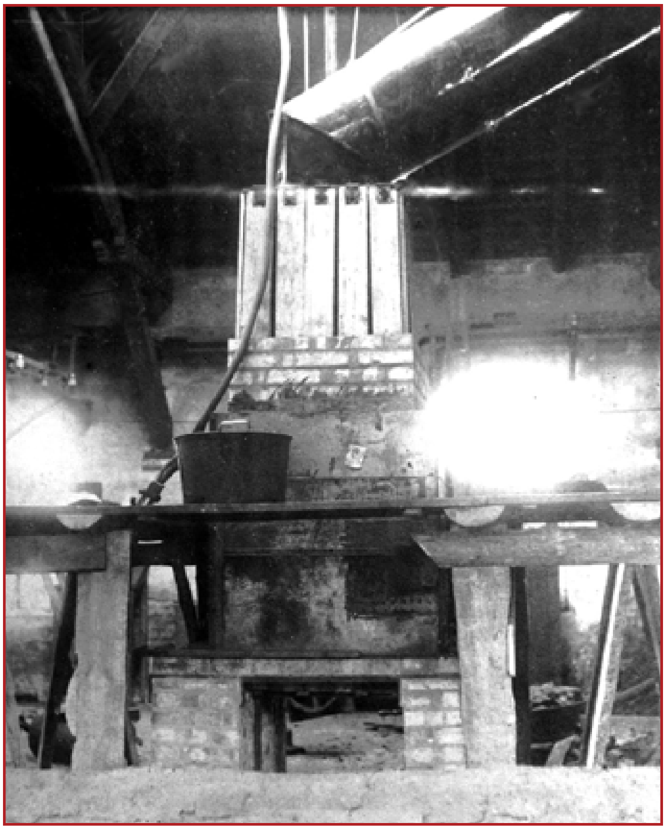

Fig. 3. *The first and oldest carborundum furnace in Benátky nad Jizerou (courtesy Carborundum Electrite a. s., Benátky nad Jizerou).*

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of various shapes and purposes made the use of bladed tools, that became easily dulled, more efficient. An oblong scythe stone, with its sheet metal sheath filled with water to keep it lubricated became the visual attribute of a farmer for most of the twentieth century. The stones are still in production and the Czech Carborundum Electrite (now Swarovski Holding) is still producing abrasives (Fig. 5). The Czech connection has not been exclusively on the manufacturing side. The crystallographic structure of carborundum produced by the Czech factory in Benatky was established by a Prague professor, F. Becke.[4]

To use the electric arc furnace, ready access to electricity was needed. The very first company to receive power from the Niagara Falls Power Company, when it opened in 1895, was the Pittsburgh Reduction Company founded by Charles M. Hall, renamed in 1907 as the Aluminum Company of America and better known as ALCOA. The second one was the Carborundum Company, founded by Edward Goodrich Acheson. His original small plant in Monongahela City used 135 horsepower of electricity and was able to produce 45 tons per year of the abrasive powder. It was then being sold at $440 a pound, less than half the price of diamond dust. Still, he was losing money until the move to Niagara, where the ability to produce the material at quantity lowered the costs and opened new markets. In 1907 the production of carborundum in the USA was reported to be 7,532,670 lb, valued at $451,960, and the only producer was the Carborundum Company at Niagara Falls. Their furnace was 30 ft in length and 12 ft wide, with power consumption of 1600 kW and current about 20,000 A.

The Columbian Expedition in Chicago created even more overseas interest. In 1894 the Austrian Carborundum Company began operating a plant at La Bâthie, Savoy, France. And in 1895 construction of a hydroelectric power station at La Bâthie was begun, with one intended purpose being the use of the electricity to manufacture more carborundum. Since then, the manufacturing of carborundum has become more international, with The Canadian Carborundum Co. established in Niagara Falls, The Carborundum Co. in Manchester, England and Deutsche Carborundum Werke in Reisholz by Düsseldorf, Germany, for manufacture of grinding wheels and sharpening stones. A German company manufacturing carborundum at Badisch-Pheinfelden has constructed a facility of 3000 hp capacity. And there was also constructed plant Gotthardwerke in Bodio, Switzerland, once the water from the Ticino River was harnessed.

Small amounts of naturally occurring silicon carbide were found in 1893 by French chemist Henri Moissan while he was examining rock samples from Diablo Canyon in Arizona. At first, he believed they were diamond crystals, but he identified them as silicon carbide in 1904. Later in his life the mineral was named *moissanite* in his honor. Moissan won the 1906 Nobel Prize in chemistry for his work in isolating fluorine from its compounds. In our story he has yet another notoriety. Just like Acheson, he also attempted to prepare synthetic diamonds through exposure of carbon to high temperature. And just like Acheson, he used an electric arc furnace of his own design (Fig. 6). He popularized the use of the electric arc in industry and in the laboratory by publishing his book *The Electric Furnace*.[5]

Acheson was responsible for numerous other chemical discoveries, including Aquadag, a graphite-based coating used in cathode ray tubes, Oildag, a lubricant additive based on colloidal graphite in oil, and an improved method for making graphite. The dag in the trade names stood for Deflocculated Acheson Graphite. Synthetic graphite had commercial value and thus the Acheson Graphite Co. was formed in 1899. The means for making silicon carbide is still referred to as the Acheson process. Acheson is the namesake of The Electrochemical Society's Edward G. Acheson Medal, which he established through a charitable gift to the Society on September 27^{th}, 1928.[6] He was a charter member of ECS and the ECS president in 1908-1909. Acheson died July 6, 1931 in New York.

Fig. 5. *Scythe carborundum whetstone and quiver, early 21^{st} century (photo author).*

Fig. 4. *Historical picture of a trade show display of carborundum products in Vienna (courtesy Carborundum Electrite a. s., Benátky nad Jizerou).*

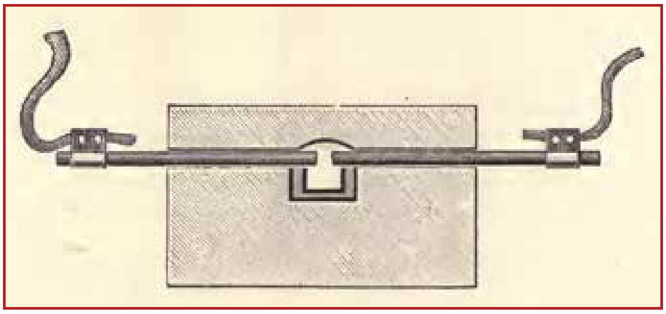


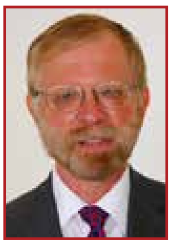
Fig. 6. *Diagram of the electric arc furnace as described by Moissan (from Ref. 5).*

Acheson observed, about his silicon carbide discovery, “You have heard that ‘fools rush in where angels fear to tread,’ and had I been a chemist, it is probable that such an experiment would not have been worthy of consideration, and certainly would not have been attempted. Be this as it may, the experiments were made with results more or less satisfactory.”[3]

Acknowledgment

This research was carried out under the project CEITEC 2020 (LQ1601) with financial support from the Ministry of Education, Youth and Sports of the Czech Republic under the National Sustainability Programme II.

About the Author



Petr Vanýsek grew up in Czechoslovakia, in the part of the country now known as the Czech Republic, where he received a doctorate in physical electrochemistry. His scientific career developed in the USA, where he went through the ranks of tenure track and tenured faculty at the Department of Chemistry and Biochemistry at Northern Illinois University. Now an Emeritus at NIU, he is currently working at the Central European Institute of Technology in Brno, Czech Republic. The Czech connection enabled him to discover the ties of early Carborundum production in Bohemia. Vanýsek has long involvement with ECS on a number of committees including four years as the society secretary. Presently, he is a co-editor of *Interface*, chair of the Europe Section, and secretary of Physical and Analytical Electrochemistry Division. He can be reached at pvanysek@gmail.com.

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