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THE CARBON FIBER DEVELOPMENT FOR URANIUM CENTRIFUGES: A BRAZILIAN COOPERATIVE RESEARCH

Paulo César Beltrão de Queiroz[1] and Désirée Moraes Zouain[2]

[1]Centro Tecnológico da Marinha em São Paulo - CTMSP
Av. Professor Lineu Prestes 2468
05508-000 São Paulo, SP
p.queiroz@ctmsp.mar.mil.br

[2]Instituto de Pesquisas Energéticas e Nucleares, IPEN - CNEN/SP
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
dmzouain@ipen.br

ABSTRACT

This paper analyzes both the carbon fiber-based development for uranium centrifuges and the research project that supports its development effort over time. The carbon fiber-based engineering properties make it a valuable supply for high technologic products. Nevertheless, its fabrication occurs only in few developed countries and there is no production in Brazil. In addition, the carbon fiber-based products have dual applications: they can be used by the civilian and military industry. Therefore, there are international restrictions related to its use and applications that justify the internal development. Moreover, the Brazilian Navy centrifuges for uranium enrichment were developed using carbon-fiber which contains polyacrylonitrile (PAN) as an imported raw material. The PAN properties of low weight, high tensile strength increase the isotopic separation efficiency. The Brazilian financial scenario surrounded by the international uncertain economy shows that combined creative project solutions are more effective. Therefore, the Navy's Technological Center in Sao Paulo (CTMSP), the University of Campinas (UNICAMP), the University of São Paulo (USP), the RADICIFIBRAS Company, and the Brazilian FINEP agency, which is responsible for the project financial support, established a partnership aiming the development of a domestic PAN-based carbon fiber industry. The innovative project solutions adopted and the results of this partnership are presented here.

1. INTRODUCTION

This study is based on part of the results obtained by the Master’s dissertation entitled “Cooperative Research: the carbon fiber development for uranium centrifuges project”[1].

The dominium of important technologies and processes, essential to the maintenance of national strategic activities, can be achieved by the conjugation of government, technological centers and firms efforts. Such alliances or technological partnerships are best known as Cooperative Research or Research Joint Ventures (RJV).

These alliances are especially useful in a scenario of short financial possibilities, when the addition of such resources, both material and intellectual, is very important to the success of any project.

The carbon fibers with the desired characteristics of high performance are materials considered of dual use, which means that it can be used for both military and civilian applications and are subject to safeguards.

Due to international market restrictions to the importation of high performance carbon fibers, the Navy's Technological Center in Sao Paulo (CTMSP), in an innovative way, developed this material to supply the ultracentrifuge production line.

The key factor to solve this problem was to put together dispersed knowledge and resources, in benefit of a national development goal.

2. COOPERATIVE RESEARCH

The context in which emerges the idea of cooperative research is much concerned to Japan and its great economic effort after World War Second.

Japanese Government encouraged its companies to share information, financing industrial consortiums focused on researches that could bring advantages in new and profitable markets.

Unlike Europe and USA, Japanese law system was more flexible concerning prevention of monopolies and industrial trusts.

Cooperation between companies aiming to develop technological innovations and competitive advantages were out of the scope of Japanese antitrust legislation, dated of 1947 (Antimonopoly Act). After the 1961 Act on the Mining and Manufacturing Industry Technology Research Association, joint ventures were encouraged and identified as a policy tool.

The Japanese authorities support created a proactive atmosphere ideal to the establishment of a more cooperative business environment, which was identified by many scholars as a key competitive advantage in international market, particularly in high technological sector.

After the success obtained by the Japanese, the US policy makers enact, in 1984, the National Cooperative Research Act and, in 1986, the Technology Transfer Act which established the Cooperative Research and Development Agreement (CADRA). Under a CADRA license, a firm could use the American government facilities (such as laboratories) and the rights for any patent obtained in a cooperative way became legally protected for all the research partners [2].

Nowadays, the cooperative research is present all over the world, especially in developed countries, counting with legal protection and government benefits.

According to the Brazilian Science and Technology Ministry (MCT), the cooperative research is one of the main tools for development, innovation and technological diffusion [3]. The term cooperative research is commonly used interchangeably with research joint venture (RJV), multclient project and consortia.

Some relevant aspects of RJV most emphasized in the literature are:

- Costs, risks and time share amongst the partners concerning to research, development, production and introduction of new products on the market;

- Shortened product life cycles;
- Employment of several types of facilities, including public laboratories;
- Government incentives;
- Participation of qualified human resources and access to academic and industrial research results;
- Access to small and medium firms;
- Solution to specific technical problems;
- Capacity to integrate university, technological community and companies;
- Synergy;
- Internalizing spillovers;
- Cost savings.

These aspects are motives or even advantages for the institutions (public and not public) to engage in such research arrangements. Internalizing spillovers are considered beneficial to the research project because firms will spend less on it, overcoming what is called the free-rider behavior. Cost savings are a decisive incentive on the formation of cooperative projects since through the sharing of research and development (R&D) costs firms can concentrate their resources and avoid wasteful costs.

In addition to the aspects above, ROLLER *et al* [4] emphasizes two other factors that motivate firms to arrange in a research joint venture:

- Product market complementarities;
- Firm heterogeneity.

There are some concerns about the formation of RJV. It is essential that a perfect knowledge of each partner´s role be achieved. Tasks, duties and rights must be clear, doubtless, for all the partners. A misunderstanding can cause frustration and lack of motivation. Trust must be kept during all the RJV and even after.

3. HIGH PERFORMANCE CARBON FIBERS

Carbon fibers are produced by the pyrolises of organic precursor fibers such as petroleum pitch, polyacrilonitrile (PAN) and rayon at high temperatures in an inert atmosphere. The term is often used interchangeably with graphite but carbon fibers and graphite differ in the amount of carbon produced and the temperature at which fibers are made and heat-treated. For example, graphite fibers are “graphitized” at 3450 to 5450^o F (1900 to 3000^o C) and essay at more than 99% elemental carbon, while carbon fibers are carbonized at about 2400^o F (1300^o C) and essay at 93-95% elemental carbon.

PAN-based carbon fibers are the dominant class of structural carbon fibers (more than 90% of all commercial carbon fibers) because of their characteristics of high performance (e.g. high strength, high stiffness, low density) and lower costs (compared to the two other raw materials: rayon and pitch). By the combination with a matrix material (commonly an epoxy resin), PAN carbon fibers form an advanced composite material, used in several applications [5].

High performance fibers are engineered for specific uses that demand an outstanding strength, stiffness, heat or chemical resistance. These properties combined with low weight make carbon fibers a very demanding material (Table 1).

Table 1. Typical properties of common structural materials

Material	Strength (ksi)[a]	Stiffness (Msi)[b]	Density (g/cm^3)[c]
Metals			
Aluminum	80 (551.6 MPa)	10 (69 GPa)	2.76
Titanium	160 (1103.2 MPa)	16 (110.3 GPa)	4.42
Steel	200 (1379 MPa)	30 (206.8 GPa)	8.00
Composites			
Glass/epoxy	250 (1723.7 MPa)	8 (55.2 GPa)	1.99
Aramid (Kevlar)/epoxy	190 (1310 MPa)	12 (82.7 GPa)	1.38
Carbon (Graphite)/epoxy	215 (1482.4 MPa)	21 (144.8 GPa)	1.55

[a] *Thousands of pounds per square inch.*
[b] *Millions of pounds per square inch.*
[c] *Grams per cubic centimeter*
Source: adapted from TRACESKI [6]

PAN Carbon Fibers are widely used in military applications (e.g. missiles, military aircraft and spacecraft structures) and in civilian applications such as wind power blades, undersea oil pipelines, sports, automotive and commercial aircraft industries, concrete reinforcement (civil engineering) and uranium ultracentrifuges (rotor tubes).

There is a growing demand for PAN carbon fibers especially due to the expansion of the aerospace industry (Boeing, Airbus, Bombardier, Embraer's new jets are constructed using more carbon fibers parts) and automotive sector. However, in the last five years, carbon fiber demand increased about 5-10% per year also because of the rising or development of new markets (wind power blades, civil engineering and undersea oil pipelines). Before the 2008 world economic crises, PAN carbon fiber demand was forecasted to grow about 15% per year until 2012 [7]. The major carbon fiber producers (e.g. Toho-Tenax, Toray, Mitsubishi, Hexcel, Zoltek, Cytec and SGL) have announced in the last three years, as a response for a growing demand, significant expansions or capital investment plans in their manufacturing capacities [8].

Because of their performance attributes, carbon fiber composites are considered critical technology. Only a few countries dominate and control the industrial process to produce both the PAN precursor and then the carbon fiber [9].

The creation of a uranium centrifuge is a huge technological challenge. The centrifuges must spin very quickly and to do that must have a very light (yet strong) and well-balanced rotors, besides high-speed bearings, usually magnetic to reduce friction. Navy's Technological Center in Sao Paulo dominates such technology. PAN-based carbon fibers, because of their properties, are used in the rotor tubes (Fig.1).

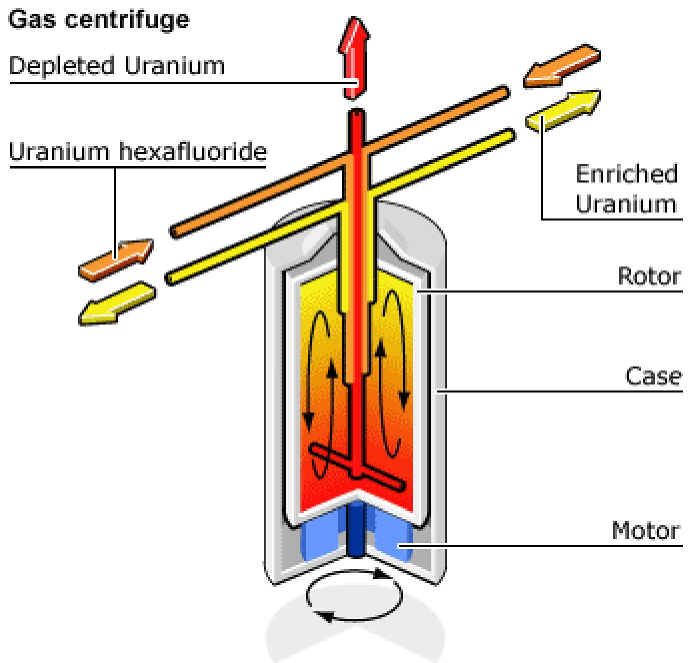

Figure 1: Uranium gas centrifuge scheme
Source: http://www.news.bbc.co.uk/…/img/gas centrifuge2_300.gif

In 2007, an American company (USEC) followed the same technological route and announced an agreement with Hexcel for carbon fiber for rotor tubes (chambers) to be used in USEC´s American Centrifuge uranium enrichment plant. There will be more than 11.500 rotor tubes for gas centrifuge machines [10].

Due to nuclear safeguards and based on international treaties (e.g. Treaty on the Non-Proliferation of Nuclear Weapons - NPT), PAN carbon fiber is a material controlled by the international community through International Atomic Energy Agency (IAEA) and other organizations (e.g. Nuclear Suppliers Group, Wassenaar Arrangement). According to INFCIRC 540 [11], the PAN based carbon fibers able to be used in uranium centrifuges rotating parts must be controlled and are subject to restrictions on its trade.

Brazilian Navy developed an ultracentrifuge based on PAN carbon fibers purchased by importation since there is no domestic production in Brazil. The Navy´s nuclear program is a peaceful one in accordance to Brazilian Constitution. Nevertheless, there were several denials for trading the PAN carbon fibers with Brazil. Such situation took Navy´s authorities to make the decision to start a program in order to develop and produce such important raw material to the centrifuge production line. Brazilian Navy has a contract with Brazilian Nuclear Industries (INB) to supply uranium ultracentrifuges.

4. BRAZILIAN CARBON FIBER PROJECT

The domestically financial scenario and the international uncertain economy that surrounds Brazil showed that combined creative project solutions are more effective. Research Joint Ventures are a very good model when it is necessary to avoid wasteful costs and optimize the short financial resources. Moreover, cooperative projects allow the partners to put together efforts, such as laboratories, knowledge and materials, in benefit of a common objective.

Therefore, four institutions, the Navy's Technological Center in Sao Paulo (CTMSP), the University of Campinas (UNICAMP), the University of São Paulo (USP), the RADICIFIBRAS Company, and the Brazilian FINEP agency, which is responsible for the project financial support, established a cooperative partnership aiming the development of a domestic PAN-based carbon fiber industry.

The Brazilian Carbon Fiber Project was established, having the CTMSP as its leader, to research and develop, in a collaborative way, the PAN-based carbon fiber.

The academic partners (USP and UNICAMP) were chosen because of their skills, academic works, researches and knowledge concerning high performance carbon fibers.

The RADICIFIBRAS Company was indicated to join the project because of its expertise on similar fibers production and also because that company had a fiber production line able to be adapted, saving costs, to the PAN precursor production line.

The CTMSP had previous research on carbon fibers, besides a well equipped laboratory for oxidation and carbonization.

The method applied to the project consisted of an exploratory study and empirical experiments using samples of selected PAN precursor fibers and PAN-based carbon fibers. These samples were imported and had the properties needed.

Basically, the project tried to reconstruct the technological route though the comparison of the Brazilian developing carbon fibers to the selected carbon fiber (imported). The two main properties of the selected material used as reference to the experiments were:
- Tensile elastic modulus (GPa): 210-230
- Tensile strength (GPa): 2.3-3.1

During the project time, the laboratories and facilities involved had investments in terms of equipment and personnel. The project had a budget of almost R$ 2.7 millions in cash, financed by FINEP.

The project was scheduled to be performed in three years, beginning in 2004. There was an extension of one year on the cooperative agreement. The tasks and activities were planned and distributed considering each partner’s competency and skills.

In Fig. 2 the activities are pointed and grouped. The diagram, identified by the authors after studying the project, shows the tasks division by skills and competencies.

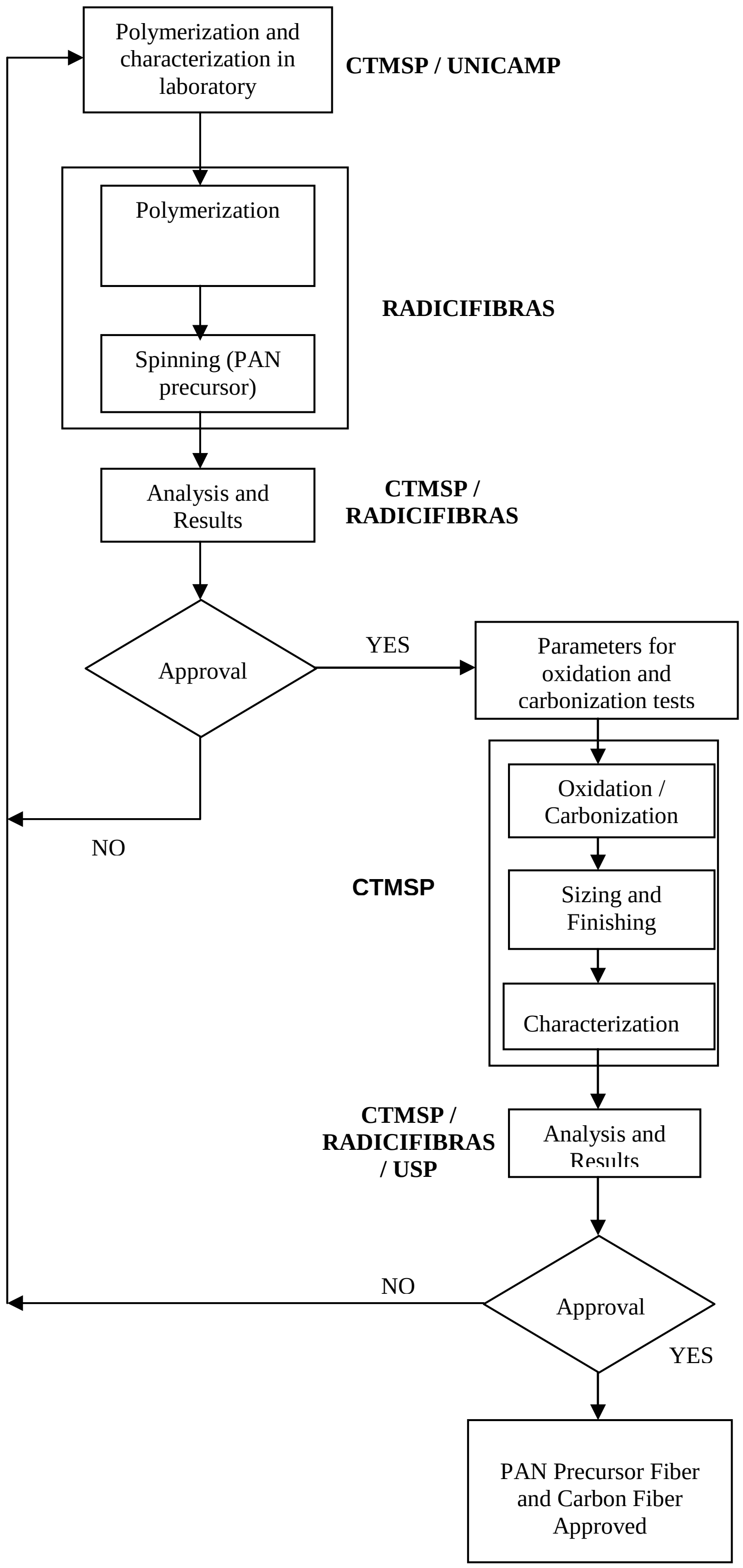

Figure 2: Brazilian Carbon Fiber Research Project activities diagram

On this study it was concluded that the RJV theory was not known by the partners and applied to the project on its beginning. However, by comparison of the aspects of a RJV (on a theory basis, cited on Section 2) to the aspects observed in the carbon fiber project, this was indeed a cooperative research or RJV project, even though not named, at first, as one. It can be listed the following aspects of a RJV observed in the carbon fiber project:

- Synergy;
- Internalizing spillovers;
- Cost savings;
- Government incentive;
- Integration (university-technological centers-firms);
- Solution to a specific technological problem (the Brazilian PAN carbon fiber);
- Qualification of human resources;
- Cost, risks and time share;
- Trustful relationship;
- Common use of each other's laboratories and facilities.

The way institutions were arranged for the project, their responsibilities, tasks and activities showed in fact an innovative form of R&D management.

The chemical and mechanical parameters and also the process involved in the PAN-based carbon fiber development are kept in secret (proprietary technology). However, there was no revolutionary innovation on the technology. The Brazilian project followed the steps of similar processes available in the world (see Fig.3).

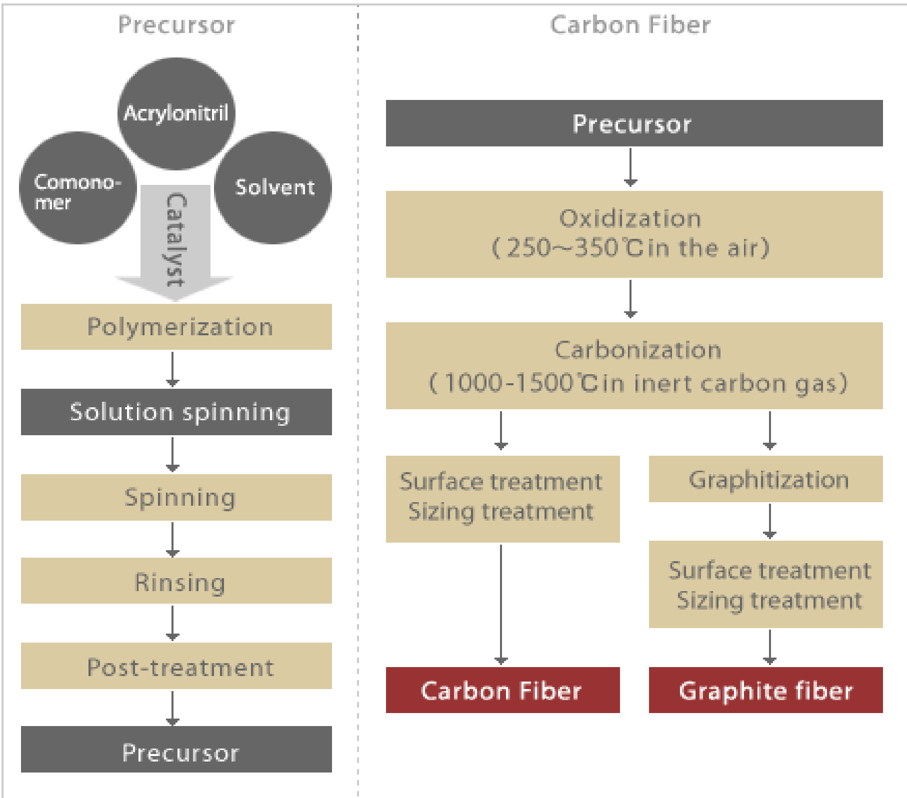

Figure 3: Manufacturing Process of Carbon Fiber (PAN-based).
Source: Toho-Tenax (http://www.tohotenax.com/tenax/en/products/pro_carbon02.php)

The project was considered successful. The PAN-based carbon fiber with the intended properties was developed. During the R&D activities, personnel qualification was improved, more than 15 academic papers were published and Brazilian industry is about to count with an extraordinary structural material that can be used not only for centrifuges, but for medical devices, wind power blades, oil pipelines, automotive vehicles, civil engineering among other uses.

Indeed, the carbon fiber developed achieved the properties expected. There was a declared intention of two huge companies (PETROBRAS and VICUNHA) to invest a considerable amount to produce national carbon fiber based on the formulation developed by the project on commercial scale. VICUNHA proposed to install PAN precursor and carbon fiber production line to supply the Brazilian market and is now negotiating the terms of an agreement with the project partners.

5. CONCLUSIONS

This study is based on the presentation of the RJV model and its benefits in a developing country such as Brazil. Especially in R&D area the investments are rare and so the efforts combination of different institutions is necessary to solve some technological problems such as the carbon fibers for the Navy's uranium centrifuges.

Cooperative research is a creative solution used in developed countries to strength and optimizes resources for specific sectors. Moreover, it is useful to congregate efforts (intellectual and material) otherwise dispersed.

The Brazilian Science and Technology Ministry (MCT) has being trying in the last few years to spread this model. It is an innovative way to achieve knowledge and development in strategic areas.

The Carbon Fiber Project conducted by CTMSP, with the participation of USP, UNICAMP, RADIFIBRAS Company and FINEP, was considered a very well-succeeded project. The results obtained were beyond initial expectations for the period. The proposal of VICUNHA Company to produce and offer to the national market the PAN-based carbon fiber formulated by the project shows that the main target was fulfilled.

Moreover, the success of the project demonstrates that it is possible to work together, academic and non academic partners, with lower costs, overcoming technological barriers to achieve a necessary and wanted development for the society.

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