# A US-Czech Republic Cooperative Research Program in Friction Materials

Zdenek WEISS; Vaclav ROUBICEK; Peter FILIP
Center for Advanced Friction Studies, Southern Illinois University, Carbondale, IL, U.S.A,
http://www.siu.edu/~cafs/, filip@siu.edu, phone +001 (618) 453 1166

KEYWORDS: *research collaboration, students' exchange, training programs, government and industry sponsored program, brake lining*

ABSTRACT: *In 1999 a Cooperative Research Program was initiated between the Center for Advanced Friction Studies of Southern Illinois University at Carbondale and the Central Analytical Laboratories of the Technical University of Ostrava, Czech Republic. The U.S. National Science Foundation and the Czech Academy of Sciences provided funding for the program. This collaboration grew out of contacts made between administrators of the two universities and a memorandum of understanding signed in 1991. Various activities and conferences were organized, and contacts between researchers were established. Important to this program was the international conference "Carbon and Carbonaceous Composite Materials" funded by the U.S. Office of Naval Research and the two respective universities. The strong association formed between the conference initiator and the local coordinator resulted in an expansion of their respective research interests and the development of the present cooperative program. In addition to the background and organizational details of the program, the paper also discusses the delineation of responsibility, and provides details on the experiences gained from the international cooperation. An important aspect is the exchanges of individual researchers and research assistants between the two institutions, as is faculty advisement of students. Another unique factor crucial to the success of the program is the training on the use of facilities not common to both institutions. This is critical to the development of a closely-knit, joint research program. The visiting faculty also offers seminars dealing with additional areas of research. The present paper also summarizes the most significant research findings emanating from the cooperation, as well as future plans and recommendations for strengthening similar future international cooperative activities in research and education.*

## 1 INTRODUCTION

This paper describes the architecture and mechanisms of a successful collaboration between two universities: SIU at Carbondale (USA) and TU-VSB Ostrava (the Czech Republic). Collaboration was initiated in early nineties on an administration level and subsequently grew out to fruitful research activities, student exchange and common research programs sponsored by Czech governments and NSF. The research program concentrates on advanced friction materials. More than 30 positions were created at CAFS SIU for Czech students. Nine master theses were elaborated within this interaction, eighteen seminars were given on both partner universities and unique research facilities and expertise are used for research and education projects. Czech and US industries were involved and benefited from this collaboration. Because of quite strong language limitations, it was not easy to generate interest of US students in traveling to the Czech Republic. It was agreed that no additional language tests are required for Czech Students involved in the collaboration, however, there is not compatibility between curricula of TU-VSB Ostrava and SIU at Carbondale, respectively, and M.Sc. degrees are not recognized. It is assumed that the common research interest of participants is the healthy driving force for a successful collaboration.

## 2 CONTACTS MADE BETWEEN ADMINISTRATORS

The Czech – U.S. collaboration grew out of contacts made between administrators of the two universities immediately after the changes in the former Czechoslovakia in 1989. Dr. John Wotiz (Professor Emeritus Chemistry) and Dr. Juh Wah Chen (Dean Emeritus, College of Engineering) from SIU and Drs. Tomas Cermak (currently Rector) and Vaclav Roubicek (currently Vice-rector) from TU

Ostrava initiated discussion of possible collaboration. Rector of TU Ostrava Tomas Cermak and President of SIU at Carbondale John Guyon signed a memorandum of understanding between the two universities in 1991. Former Vice-rector Vaclav Roubicek and Provost Benjamin Shepard defined overlapping areas of interest between their respective universities. As a natural development, collaboration began in areas of coal research. John Mead, Director of the Coal Research Institute became involved and several student exchanges were proposed. Various activities and conferences were organized, and more intense contacts between researchers were established. The first "scientific contacts" were made before organization of the conference "Carbon and Carbonaceous Composite Materials: Structure-properties relationship organized in the Czech Republic on October 10 to 13, 1995. VSB-TU Ostrava, SIU Carbondale and U.S. Office of Naval Research founded this conference. This conference was very successful and papers were published in book Carbon and Carbonaceous Composite Materials edited by Palmer, Marx and Wright [1]. Scientists from VSB-TU Ostrava and SIU Carbondale were presenting almost 25% of all contributions and along with colleagues from around the world contributed significantly to the success of the conference. At this time, several meetings were organized and possible scientific projects were discussed. These involved activities in Carbon studies, Biomaterials and Environmental Aspects. The strong association formed between the conference initiator, Dr. Maurice A. Wright, and the local coordinator, Dr. Peter Filip (current Director of the Center for Advanced Friction Studies at SIU in Carbondale), resulted in an expansion of their respective research interests and the development of several scientific projects, including the present cooperative program. Originally, Dr. Filip was invited to SIU Carbondale as a Visiting Scholar in 1996 and led research program related to polymer matrix composite materials at newly formed Center for Advanced Friction Studies. Presentation related to On-Highway and Off-Highway friction composite materials made by Wright and Filip in New Orleans (1996), Tampa (1997), Sam Francisco (1998) and Leoben (1998) [2-5] attracted more industrial partners and strong financial support allowed to establish widely accepted scientific program. Later, Dr. Filip took over and directed the research in Carbon/Carbon and ceramic matrix composite materials. He became a new Director of the Center for Advanced Friction Studies and continued in collaborative effort. As a result more than 30 positions for Czech students and researchers at SIU Carbondale have been created. M.Sc. and Ph.D. programs were initiated. However, it is not easy to attract U.S. students for programs organized in the Czech Republic. This is related to language barriers.

## 3 SCIENTIFIC COLLABORATION AND DESCRIPTION OF PROJECT

The cooperative program was realized in several areas:

**Area 1** involved the participation of both institutions in a research designed to define the parameters that influence the performance of friction materials. One part of research activities was oriented on frictional properties of phenolic resin bonded materials and second part of activities was devoted to the research in carbon/carbon and ceramic composite friction materials. Principal investigators for phenolic bonded materials area were Drs. Filip (SIU Carbondale), and Weiss with Roubicek (TU Ostrava), principal investigators in carbon/carbon area were Drs. Filip Wittmer (SIU Carbondale), Weiss and Roubicek (TU Ostrava). **Area 2** involved travel of research assistants between the two participating institutions for the purpose of participating in the research program. **Area 3** involved the US principal investigators traveling to the Czech Republic to present seminars, short lecture courses, and engage in consultations dealing with friction materials to TU Ostrava and industrial personnel. **Area 4** involved the Czech principle investigators traveling to the USA to present seminars, short lecture courses and engage in consultations dealing with the characterization techniques developed for friction materials. Three Ph.D. dissertations and research assistants exchanges were initiated, each in one of above mentioned research areas. Drs. Weiss (TUO) and Filip (SIUC) supervised Mrs. Monika Kristkova and Drs. Weiss (TUO) and Filip (SIUC) supervised Mrs. Grazyna Martynkova. All Ph.D. students were performing research at SIU Carbondale (sponsored by this program) and two of them finished their work in Ostrava in October 2003. Drs. Roubicek, Weiss and Filip were on committees and participated in students' examinations. Mr. Adam Pawliczek will finish his Ph.D. study in spring 2005 and is currently completing his 12 months stay in Carbondale. Dr. Wright and Dr. Filip gave seminars at TU Ostrava, and Dr. Weiss and Dr. Roubicek gave seminars at SIU Carbondale. Skoda/Volkswagen Group (Czech user of friction materials) and Honeywell and Federal Mogul (US producers of friction materials) industries were involved into research

and US materials were tested for Czech car industry. Skoda/Volkswagen Group Company provided testing cars and performed field tests in Austrian mountains and also in laboratory using a brake dynamometer. Honeywell and Federal Mogul Company (Ferodo-Pagid) submitted friction materials. All companies gained information from this research. It was presented to Skoda/Volkswagen Group in form of report and Skoda/Volkswagen Group co-sponsored the research by 1,500,000 Czech Crowns (approximately $39,500). Principal investigators (Weiss, Roubicek, Filip) visited partner universities. Eight visits were paid to partner from both universities.

### 3.1. Research activities in phenolic bonded materials

In accordance with proposed planned work, both universities shared their expertise and facilities as planned and as shown in Table 1. XRF, FTIR, GC-MS, XRD, SEM, TEM, EDX analyses were performed on samples, which were submitted to systematic friction testing. Friction experiments in field conditions (downhill driving of passenger cars) and in laboratories (brake dynamometer and Friction Assessment and Screening Test) were conducted as planned. Examples of obtained performance results from friction tests are given in Fig. 1 a and b, characteristic morphology of a friction layer is given in Fig. 2, and GAXRD results ads obtained after dynamometer brake lining tests are in Fig. 3.

Table 1. Sharing of experiments and expertise.

| CAFS SIU Carbondale | TU Ostrava |
|---|---|
| Light Microscopy (white, polarized light) | Gas Chromatography |
| SEM with EDX | Mass Spectroscopy |
| TEM with EDX | XRD, GAXRD |
| XRD, GAXRD | FTIR |
| Thermophysical Properties | AAS |
| Friction Tests | ICP |
| Sample Formulation | XRF, Chemical Analysis |

Attention was paid to evaluation of friction layer, generated at different braking conditions and temperatures generated.

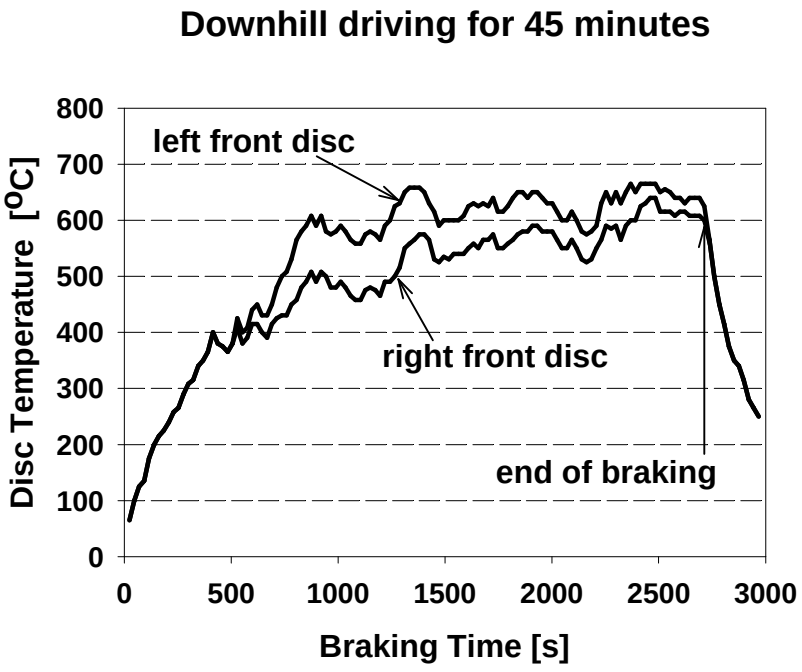


Figure 1a. Field test, Skoda Felicia brake lining sample A (Skoda/Volkswagen Group).

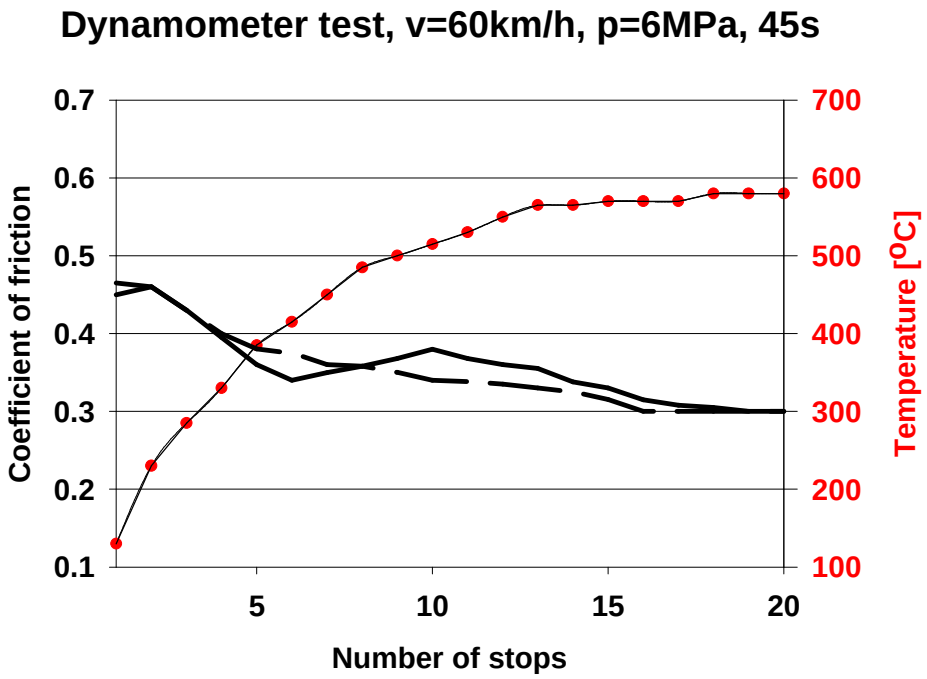


Figure 1b. Dynamometer test, brake lining sample A (Skoda/Volkswagen group).

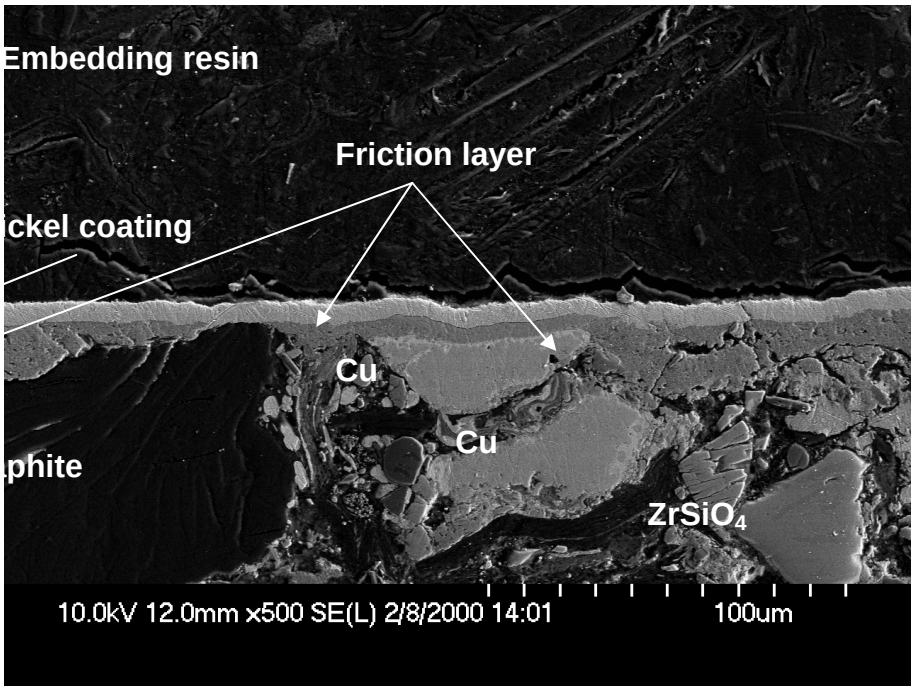


Figure 2. Characteristic friction layer developed on the friction surface of sample tested in brake dynamometer at 700°C. Perpendicular cut with respect to friction surface. SEM.

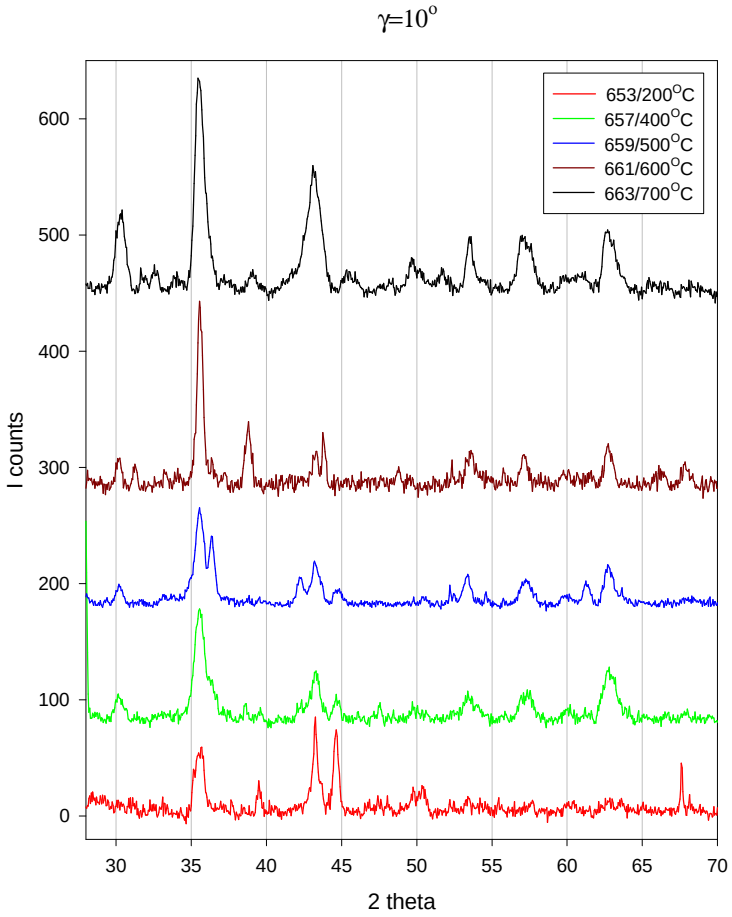

Figure 3. GAXRD (γ=10°) experiment performed after dynamometer tests at different braking conditions. Sample A.

Character of friction layer dictates the performance of investigated composite materials and from practical point of view represents one of the most important characteristic of a friction material. Based on combination of techniques and expertise from both universities, the reactions on the friction surfaces were described. New technique – grazing angle X-ray diffraction (GAXRD) was developed and the friction layer was thoroughly analyzed using the combination of GAXRD with electron microscopy and energy dispersive microanalysis (SEM, TEM, EDS), as well as special light microscopy techniques.

A very important finding is that testing in laboratory and field can be correlated. The correlation is based on the analysis of the same friction layer generated on the friction surface after two mentioned testing procedures. Scientific analysis of processes on the friction surface confirmed that it is possible to use engineering techniques, based on measurement of temperature, inertia and torque, to predict the performance of brake lining materials. The results are published in [6].

Based on achieved results, the future three-year project was planned. Proposed collaborative research between CAFS SIU Carbondale and CAL TU Ostrava will contribute to developing a “tool” which will be based on understanding of friction process fundamentals, analyzing real chemical and physical processes on the friction surface and allowing tailored design of advanced friction materials. Based on our previous experience, this research necessarily has to involve following steps (see Filip P., Wright M. A., Kovarik L. et al. Quarterly report to CAFS, March 1999 and Quarterly report to CAFS, June 1999):

1. Selection of model materials.
2. Performance of representative friction tests.
3. Analysis of processes on the friction surface.
4. Application of fundamental laws (thermodynamics, kinetics) for description of fundamentals.
5. Synthesis and tailored design.

Our three-year research will cover **first three points**. Further collaborative effort will be devoted to **last two points**. Model formulations will be selected by using the database generated at CAFS in 1996 to

1999 period and based on our collaborative activities within last year. These materials should involve three fundamental material groups:
-Polymers
-Metals
-Ceramics and glasses (this group involves also minerals frequently applied in formulations).

### 3.2. Carbon-Carbon Materials Research

Carbon-carbon composites have been fabricated using carbon fiber preforms into which various pitch fractions were infiltrated. Each fraction, Alpha, Beta and Gamma were first separated using conventional solvent extraction techniques. The resultant composites were then carbonized and then densified using chemical vapor infiltration.

Finally, heating to a temperature of about 2600 Deg C carried out graphitization. A typical area of a composite infiltrated with a Beta pitch fraction is shown in Fig. 4.

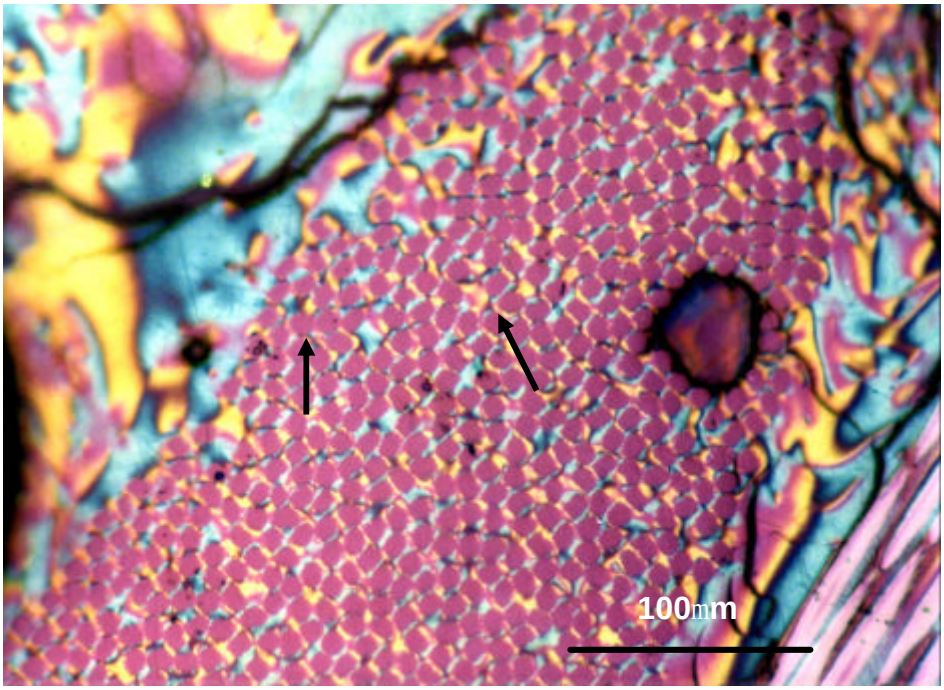

Figure 4. Light microscopy of carbon-carbon composites using beta resin fraction.

Friction tests were performed on composites infiltrated with all three fractions. The results, though preliminary, indicated that the performance of the material produced from the Beta fraction was superior, as shown in Table 2

Table 2. Performance of tested samples.

| | Friction force [N] | Time [min] | Wear in terms of weight loss [%] | Average μ |
|---|---|---|---|---|
| **Alpha** | 77.4 | 20 | 41 | 0.34 |
| **Beta** | 77.4 | 20 | 27 | 0.45 |
| **Gamma** | 77.4 | 20 | 78 | 0.21 |

This initial work studying the friction performance of pitch matrix composites indicates that high performance can be achieved; however, more work is required to establish optimum fabrication

conditions. And, larger test specimens need to be fabricated and tested to simulate actual operational conditions.

## 4 CONCLUSIONS

A common research interest and active involvement of scientists, researchers and students into collateral projects is a key attribute for success of this collaboration. Administrative contacts were very important in the first stages of interaction and created conditions for a successful interaction between scientists. It is not easy to solve compatibility problems between two different curricula.


## ACKNOWLEDGEMENTS

Authors would like to acknowledge financial support made by NSF and GA CAV (Cooperative Agreement No. EEC-9523372).


## 5 REFERENCES


[1] K.R. PALMER, D.T. MARX, M.A. WRIGHT (EDS.) *Carbon and Carbonaceous Composite Materials – Structure-Property Relationship.* World Scientific Singapore, 1996.

[2] J.C.CRELLING, P.FILIP, M.A.WRIGHT. *Petrographic characterization of carbon and other components in automobile brakes*. CARBON'97 Extended Abstracts and Program, PenState Univ. Vol.II, 1997. 224.

[3] J.C.CRELLING, P.FILIP, M.A.WRIGHT. *Characterization of carbon and other components in automobile brakes with density gradient centrifugation*, CARBON'97, Extended Abstracts and Program, PenState Univ. Vol.II, 1997, 226.

[4] P.FILIP, L.KOVARÍK, M.A.WRIGHT. *Automotive Brake Lining Characterization*, Proc. of 15th Annual SAE Brake Colloquium 1997, P-319, SAE Warendale, PA, 1997, 41-61.

[5] P. FILIP, M. A. WRIGHT: *Characterization of composite materials for automotive braking industry. Practical Metallography,* Special issue 30, 1999, 449.

[6] D. RAFAJA, Z. WEISS, P. FILIP. *On Friction Layer Formation in Polymer Matrix Composite Materials for Brake Applications.* Wear 252, 2002, 189-198.