# A 20 –YEAR EVALUATION OF MEDIAL EXPERIENCES WITH CARBON FIBERS IN POLAND

M.Blazewicz\*, S.Blazewicz\*, J.Chlopek\*, E Pamula\*, C.Wajler\*, A Gorecki\*\* \* University of Mining and Metallurgy, al.Mickiewicza 30, 30-059 Cracow, Poland \*\* Medical University Department of Orthopaedics, Lindley str.4, 02-005 Warsaw, Poland,

## Introduction

Carbon fibers as a biocompatible materials has been used before 1977 in orthopaedic field as an artificial ligament [1,2]. In Poland, carbon fibers experimental studies began in 1982. Specially prepared carbon fibrous devices as prostheses of knee ligaments and Achilles tendons have been clinically used since over 15 years.

Many patients have been subjected to implantation of carbon fibers prostheses in the form of braids at reconstruction and replacement the medial, lateral collateral ligaments, acromioclavicular and clavicular joints [3]. Carbon fibers in the form of uwoven fabrics were applied in the treatment of cartilage defects of patellae and in dermatology. Authors' own results indicated that the biological behavior of carbon fibers depends on the structural and microstructural parameters. Some aspects of preparations, structure and properties of fibrous carbon implants with respect to their biological behavior are discussed.

## **Experimental**

The manufacturing process for carbon fibrous implants has been reported elsewhere [4]. The implants were prepared in the form of braids and unwoven fabrics. These two forms of carbon implants were investigated in soft and hard tissue. Different parameters of carbon fibers were analyzed (crystallinity, surface state, carbon purity) from point of view of biological behavior. The method of carbon braid production provided the possibility to obtain low crystalline fibers of increased strain to failure and chemical reactivity in biological environment (tab.1). The surface of fibers was modified in order to obtain acidic or basic functional groups. The fibers chemically modified were characterized by a high content of phase rich in oxygen, nitrogen and hydrogen. Properties of carbon fibers in the from of unwoven fabric are gathered in table 2.

# **Results and Discussion**

The infrared spectra of modified carbon fibers in the form of braids and of typical technical carbon fibers are shown in figure 1. The spectrum of the fiber after modification (active fiber) indicates the presence of oxygen-carbon and hydroxyl – carbon bonds. The experiments revealed that such carbon undergo in biological environment implants physical and biological transformations. The intensity of these processes depends on structural and microstructural parameters of carbon implants. Physical process is mainly developed by gradual fragmentation of carbon fibres. Such a process was observed in the case of carbon fibres obtained at higher temperature of carbonisation of organic precursors ( see tab.1 , carbon braid obtained at 2700 <sup>0</sup>C). This type of fibers, having similar properties to the technical fibers, behaves as inert material in biological environment ( soft tissue), which means that they are not subject to biological degradation in living body and the only observed mechanism is fragmentation process in smaller fragments of particles. Low- carbonized carbon fibers behave differently from the technical ones, namely they undergo partial fragmentation and react with biological environment being gradually resorbed in the implantation site. The resorption of carbon implants by host's tissues led to decreasing the fiber diameter and structural transformation of carbon structure resulting form partial oxidation. Such fibers are more easily assimilated by the living organism.

The results indicated distinct influence of the surface state of carbon fibers in the form of unwoven fabrics on macrophage activity and on bone tissue healing. The different rates of bone wound healing were seen in histological studies. The presence of acidic groups on the surface of implant enhanced phagocytosis of the material by macrophages in soft tissue, while the basic groups on the carbon surface was advantageous for regenerative processes of bone tissue (tab.2).

The in vivo examination revealed good biocompatibility of low –carbonized carbon fibers , their ability to stimulate growth of connective tissue and resorption in organism., that have been confirmed in the research, provided the background for development of temporary tendon and ligament implants in the form of braids.

These materials are particularly recommended for some specific parts, such as the knee ligament, shoulder joints and Achilles tendons.

Experiences with low – crystalline carbon fibers in the form of unwoven fabrics appear to provide the optimal environment for regeneration of tissue in intra - articular sites. Owing to the spatial architecture of fibers and their chemical modification the cells can penetrate and overgrow within the implant scaffold with a connective tissue without producing the foreign body reaction. The composite structure of the scar permits early loading without deformations of the reconstructed joints surface. These materials can be an alternative way in the treatment of the knee cartilage before the prostheoplasty.

## Conclusions

The study showed that biological behavior of carbon fibrous materials may depend on the type of single fiber, its structure, chemical surface state and elemental composition.

Biological properties of fibrous carbon materials justify further studies on determination the range of their application, methods of implantation and processing of carbon materials designed specially for medical purposes.

## References

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#### Acknowledgements

Research sponsored in part by the Polish State Committee for Scientific Research grant No.PBZ/KBN/13/T-08/99



Fig.1 FTIR spectra of carbon fibers with a highly ordered structure (a) and of active in biological environment (b)

processing	strain to	fiber	structural parameters					
temperature,	failure,	diameter						
[ <sup>0</sup> C]	%	μm	L <sub>c</sub> , A	L <sub>a</sub> , A	d <sub>002</sub> , A			
1200	3.2	8.3+/-0.4	11,4+/-0.8	-	3.55			
2700	1.8	8.0+/-0.2	50,2+/-2,8	127+/-8.9	3.37			

Table 1. Parameters of carbon braids

Table 2. Physical and chemical parameters of unwoven carbon fabrics

type of sample	concentration of	elementary analysis,				Purpose		
		[% wt]						
	acidic mol[H <sup>+</sup> ]/g	basic mol[OH <sup>]</sup> /g	С	N	Н	0	ash	
Acidic surface	$3.4 \times 10^{-3}$	9.8x10 <sup>-4</sup>	81.0	6.0	0.8	9.0	3.2	Scaffold for
groups								soft tissue
Basic surface	3.3x10 <sup>-5</sup>	$6.2 \times 10^{-4}$	86.4	4.9	0.5	6.8	1.5	Scaffold for
groups								hard tissue