BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

Faculty of Mechanical Engineering

Summary of PhD dissertation

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M.Sc. in Mechanical Engineering

M.Sc. in Biomedical Engineering

PASSIVE AND ACTIVE COATINGS AND COATING TECHNOLOGIES OF CORONARY STENTS

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Research objectives

The objectives of my research were developed by the followings:

- Development of a professional system to qualify commercially available coated coronary stents.
- Recognition of the effects of the coating technology parameters for the morphology of the coating, then in view of this production of different structured coatings.
- Production of adequate and appropriate coatings for drug delivery with different coating technologies. Investigation of the drug-distribution and the drug-elution of drug eluting stents.
- Modification of the surface roughness and the investigation of adhesiveness of the coating.
- Development and testing of an appropriate method for measuring the stent retention, then the determination of the main parameters which can affect the value of the stent retention.

Completed research work and results

In this dissertation an alternative professional system of coated coronary stents was developed and with it the optimisation of technological parameters was successfully achieved. The values of stent retention were measured for coated and uncoated stents using two methods, developed by me, as part of the research.

It was necessary to carry out an extensive survey of literature available in order for me to successfully complete my investigations. In this field of study, it is also important to have Interdisciplinary knowledge, so that is possible to focus on and understand the detail of both engineering and medical publications.

In the case of the applied complex professional system the full-scale determination of the coating-specific properties were provided. Therefore, this method can also be used for the basics of the decision-making of doctors and with this, the product-parameters and functional properties of coated stents, can be qualified. To successfully perform the whole examination-series, which will determine all of the characteristic parameters of the coatings;

three uniform coated coronary stents are necessary in the case of passive coatings, while four will be required in the case of active coatings.

From the investigation of the coated stents and the findings of my literature research, polymer coatings were developed using dipping and micro spray methods. In case of the electro-polished samples the adhesiveness of the coatings was not as good when compared to the etched ones. My findings demonstrated that the adhesiveness of the coating is weaker when the surface is more uniform and smoother. Despite this, only the etched surface is not suitable for direct coating.

The micro spraying is more favourable when we want to create a coating which is suitable for carrying drugs and with the dipping method, with the right parameters, both smooth and porous coatings can be achieved.

To create a smooth, non-porous coating 1 wt% PUR solution is necessary. Furthermore, to create porous PUR coatings the 2 wt% solution is optimal. In the case of both coating types, the application of dipping is required 3 times and will result in the optimal coating parameters being achieved. However, using the micro spraying method to create a porous coating, 2 layers of the 1 wt% PUR solution was found to be sufficient. From the polyurethane coatings examined, the hydrophilic coatings released a higher volume of drugs than the hydrophobic ones.

Two different methods were developed to measure stent retention; the first one is with an adhesive layer and the second one with a pull-off edge. Both methods are necessary to simulate the different cases. The results are comparable with the adhesive layer method, but with the pull-off edge method the increased forces caused by the failed balloon need to be taken into account. In case of the adhesive layer method the balloon remains intact and the stent can be removed without any damage, but with the pull-off edge method the balloon is torn and the stent becomes crumpled. The measurements were performed using different speeds, in air or in ionized water.

Theses (New scientific results)

1. thesis [1,2,3,4,5,6,7]

During the course of my studies I have developed a professional system to qualify coated coronary stents and from this the coating specified properties can be determined. As parts of this professional system, I developed new investigational methods. My work also involved optimising this system and in doing so established how to successfully perform the whole examination-series, which will determine all of the characteristic parameters of the coatings; three uniform coated coronary stents are necessary in the case of passive coatings, while four will be required in the case of active coatings.

2. thesis [8,9,10]

As a result of the examination of surface roughness and the adhesiveness of Chronoflex®-coating, I have with extensive testing, proved that it is necessary to use an electrochemical treatment, with the result R_a=1.5-2.0 µm roughness, to achieve the strongest adhesion of stent-coatings. This value is the possible maximum achievable if the stent production technology material removal characteristics are considered.

3. thesis [8,9,10]

Through my research, I have determined that to produce a smooth, porous-free coating by dipping method, 1 wt% of polyurethane solution is necessary. In addition, I have also determined that, to produce porous coatings by dipping method, 2 wt% of polyurethane coating is the optimal. In case of both coating types dipping three times will result with the optimal coating properties. To produce smooth, non-porous coatings using the solution at room temperature, together with slow drying is necessary.

4. thesis [8,9,10]

The most appropriate, porous coating can be achieved by using the dipping method and fast drying with all three coatings. In case of Carbothane®, the porous coating can be produced with the combination of fast drying and ultrasonic treatment. From my findings, I also have determined that a single dip in the applied technological window, the porous structure did not evolve.

5. thesis [8,9]

I have characterised the distribution, the quantity and the spatial dimensions of the pores with the index of porosity. The index of porosity determines the drug delivery ability of the stent coating. I have proved with measurements that the increasing value of solution concentration and the number of the layers increase the porosity index and between

2-4 wt% solutions 0.25-0.35 $\mu m^3/\mu m^2$ value of drug is carriable.

6. thesis [4,7,11]

As a direct result of my project, I have developed two examination methods to determine stent retention; the first one is with an adhesive layer that simulates and determines the obstructions in the narrowed sections of the arteries; and the second one with a pull-off edge, which simulates the blockage at the entrance of the arteries.

I have appointed the stent retention as the functional property of the delivery system using the pull-down test. The stent retention can be characterised with the "specific stent stripping force". From this, I found the PUR coating and the increasing value of the pull-down speed also results in an increase in the specific stent stripping force. In the case of Chronoflex® coated stents the specific stent stripping force has increased from 0,45 N/mm until 0,76 N/mm due to the increased pull-down speed.

Publication of the new results

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