12 CONCLUSION

The increasing interests in the use of polymer-metal compounds as well as the discussion of the interactions between substrate and layer (using polypropylene as matrix material) led to the setting of tasks for this work. The contribution of the pretreatments and the metallization processes is discussed. The interface analysis represents an important aspect of the investigations.

For the production of the polymer-metal compounds three different polypropylene substrates were used. The use of additives (material N 84) as well as grafting with maleic acid anhydride (mateial E 15) affect the strength in the compounds positively. However this influence is to be recognized with the PP-PT-Cu compound as with the PP-DACH-Cu compound.
Altogether it was stated that the modifications in the matrix materials can represent an improvement for the bond strength. In the considerations for the production of a polymer-metal compound of high adhesion this possibility should be considered.

One of the surface modifications is the *mechanical pretreatment*. The SiC sandpaper of the granulations 500 and 220 used in this work leads to an increased specific, chemically reactive surface. Between the surface roughness and the bond strength in the compound a direct correlation was determined. The more highly the roughness the more largely the bond strength. However the mechanical pretreatment is not sufficient alone in order to receive a satisfying adhesion. Therefore further pretreatment were used. The mechanical adhesion model is not suitable (at least in the case of the polypropylene-copper compound), in order to secure an optimal strength and qualitatively high-quality layers.

One of the important surface modification in this work is the *low pressure plasma treatment*. The plasma gases oxygen, nitrogen and helium were used. The best results as to the strength were obtained with oxygen. During the plasma process oxygen functional groups are built into the subtrate surface by this reactive plasma gas. By means of the XPS analysis it was deteremined that this functionalities mainly contain (C-O)-bindings (hydroxyl- and/or ether groups). But it must be said, that the influence of the plasma treatment on the adhesion becomes clear only by the use of a polymeric intermediate layer, because the obtained pull-off strength fails very low at the pure polypropylene copper compound ($\leq$ 0,8 MPa). However the low pressure plasma treatment places itself as a necessary pretreatment process in order to achieve a good adhesion between the polymeric intermediate layer and the polypropylene.
For the plasma gas oxygen it was determined a direct correlation between the wettability of the plasma treated substrate and the pull-off strength of the compound. A short treatment time makes a high degree of wettability and a high strength possible. With increasing process time (in the available work max. to 60 s) worsen both the wettability of the substrate and the bond strength. This result shows that the optimal treatment time in the oxygen plasma represents an important aspect regarding a good adhesion. The optimal treatment time in this work are 10 s. By a longer treatment with this orifice gas it comes to the development of low-molecular-weigth-oxydized-molecules (LMWOM’s) on the surface, which are characterized by a small adhesion on the substrate. The AFM analyses supply a reference to the LMWOM‘s. A clear degradation of the surface morphology and a comparatively strong graining of the surface are to be registered from the short to the long treatment time.
The pull-off strength determined after the treatments with the plasma gases nitrogen and helium are smaller. It is assumed that the nitrogen functional groups are responsible, which are determined with XPS after the plasma modification of the polypropylene with both gases.

The combination mechanical pretreatment / plasma modification can improve the adhesion-improving effect with the used polymer polypropylene. This means that both the change of the topography (larger specific surface) and a larger surface tension (with a increased part of the polar groups) have a important influence of the adhesion.
As previously mentioned, the small pull-off strength in the pure PP-Cu compound leads to the use of polymeric intermediate layers for the adhesion mediation.

The chemically synthesized *polythiophene layer* is strongly hydrophilic, which is expressed in a high surface tension. In addition it possesses a sufficiently high conductivity, whereby the direct galvanic copper plating is possible. Beside the galvanic process the vacuum evaporation is used. An influence of the metallization process on the pull-off strength can‘t be determined. Mechanical roughening of the substrate represents a necessary factor for a good adhesion in the PP-PT-Cu compound. With increasing roughness of the polypropylene surface a pull-off strength of max. 3,0 MPa were obtained. Beside the surface roughness the values are depend from the substrate (type of polypropylene) and the plasma modifications. In all cases the compound breaks in the interface polypropylene / polythiophene. The break can be regarded as pure adhesion break. Between both polymers thus only physical interactions are probable. Between polypropylene and copper exist substantially stronger interactions. Even chemical bondings are probable.
The determined maximum pull-off strength can be regarded as satisfactory. In view of the necessary mechanical roughening of the substrates it requires further investigations, because the aim of this work is the production of a polypropylene-copper compound without mechanical pretreatment of the polypropylene.

The layer from *diaminocyclohexane*, manufactured during a plasma polymerization process, has excellent adhesion characteristics. The power of the plasma source and the process time turn out as important factors of influence. The correlation between the parameters of the plasma polymerization and the strength consists of the fact that the pull-off strength becomes larger with increasing RF-power and process time. It is assumed that the higher RF-power involves a stronger fragmentation of the DACH layer and therefore a better bonding to the polypropylene (chemical bonding). Larger and homogeneous layers can be produced by the longer process time, which positively affects the adhesion. Beside the parameters of the plasma polymerization the mechanical pretreatment affects the adhesion clearly also at the compound PP-DACH-Cu just like at the PP-PT-Cu compound. The probably most important aspect with the production of the group is that the mechanical pretreatment of the substrates is not necessary in order to achieve a high adhesive strength. During the use of a RF-power of 300 W and a process time of 60 s a maximum pull-off strength of 2,2 MPa is determined. With increasing roughness of the polypropylene surfaces (comparably with compound PP-PT-Cu) the pull-off strength also increases (max. to 3,9 MPa). By the extension of the plasma polymerization process on 180 s the strength in the compound of the mechanically not pretreated substrates is deteremined with ≤ 4.2 MPa. These values explain the substantially stronger interactions of the diamino-cyclohexane with the polypropylene opposite to the polythiophene. The break of this com-pound takes place mainly in the boundary layer PP / DACH, i.e. in a small degree a break in the polymeric intermediate layer was observed. Therefore and due to the high values of the pull-off strength it is assumed, that for the adhesion between these two polymers both physical interactions and chemical bondings (even if only to a small part) are responsible. The adhesion between the diaminocyclohexane and the copper is stronger. In this case mainly chemical bondings are assumed. These can exist in the form C-O-Cu due to the high oxygen content of the DACH layer (≈ 24 %).

The aim of this work was the production of a polypropylene-copper-compound of a sufficient strength without a mechanical pretreatment of the substrates. This is succeeded by the use of an intermediate layer of a plasmapolymerized diaminocyclohexane, whereby the parameters of the plasmapolymerization are of decisive importance. Despite the good results it must be said that the compound requires further investigations. It is to be assumed that the pull-off strength can be further increased by the extension of the process time, which couldn‘t be accomplished for technical reasons. An increase of the power of the plasma source (RF) isn‘t recommended due to the strong thermal load of the substrate.
In principle the mechanical pretreatment just like the low pressure plasma treatment leads to an improvement of the strength in the compound. Both pretreatment methods represent necessary however no sufficient processes for the adhesion improvement. Regarding to the adhesion the plasma polymer layer exhibits clear advantages in relation to a layer from the intrinsically conducting polythiophene.

A connection between the practical results and the adhesion models is to be determined only conditionally. The adsorption theory is to be favored. The interactions specified in this theory explain the wetting and/or the strength of two contact partners. Physical interactions are to be favored for the boundary layer polypropylene / polymeric intermediate layer. These interactions contain e.g. Van der Waals forces. In addition hydrogen bonds and Lewis acid-base interactions can be contained. With chemical bondings is not to be counted between polypropylene and polythiophene but between polypropylene and diaminocyclohexane in a small degree. However this form of the interactions might be favored for the interfaces polythiophene / copper as well as diaminocyclohexane / copper.