

# Electrically-Responsive Reversible Thermoset Polymer

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**Date:** 09-07-2019

## Abstract

This study examines the preparation of electrically conductive polymer networks based on functionalised polyketones with furfurylamine (furan) and 4-(aminomethyl)benzoic acid (Pamba) moieties added with multi-walled carbon nanotubes (MWCNTs) and reversible cross-linked with bis-maleimide via Diels-Alders reaction. The polyketone30 (Ethylene/propylene 30/70) reacted with furan and Pamba in 60/20 ratio. The spectral analysis showed no presence of Pamba and concluded was that only furan had reacted. The Pk30-Fu60 composition was further investigated instead. The addition of MWCNTs made the material thermally and electrically conductive. The cross-linked composite has a higher modulus with 2.5% MWCNTs than with 5.0%, but on the other hand the softening points are staying almost the same for the different percentages of MWCNTs in the bars and are around 90°C. The glass transition of the composite increased from 39°C to 66°C after crosslinking. With all the different percentages of MWCNTs an electrical current was applied and showed a strong current for 5.0% and 2.5% while not much voltage was applied. After cutting the bar containing 5.0 wt% MWCNTs the reversibility was tested and showed electrical self-healing already between 13-19 V.

## Introduction

Conductive polymer nanocomposites consist of e.g. carbon nanotubes, metal nanoparticle and graphene together with polymer matrices, which have increased in activity in the composite material study. Due to their great mechanical and physical properties, like easy processing, low density and flexibility, these polymers are useful in electrical applications such as electromagnetic interference (EMI) shielding, sensors, flexible electronics and thermoelectric devices. [1]

To fabricate a conductive polymer nanocomposite, polyketones (PK) can be used. Aliphatic polyketones are terpolymers produced from carbon monoxide, ethylene and propylene with strong polar ketone groups in the backbone which is giving the polymer strong attraction between the chains. The ketone backbone gives the whole polymer great functionalization to confer the polymer to materials with increasing potential. The polyketones can react via mild Paal-Knorr reaction with nitrogen-functionalized amines with pyrrolic function. With this functional group can be tuned to desirable values for thermo-mechanical properties. The usage of furan-grafted polyketones promotes the thermos-reversibility of cross-linked polymers due to Diels-Alder (DA) and re-DA reactions when desired heat is applied to the furan moieties. These reversible reactions give the PK self-healing character with the ability to restructure and recycle in order to extend the product service life. [2]

The covalent furan attached to the PK can react with bis-maleimide (B-Ma) to get the crosslinking. Around 50°C the furan and B-Ma will crosslink and break (de-cross-linked) at about 120°C. This is occurring with fast reaction kinetics without help of a catalyst. This reversible reaction can occur multiple times having very small degradation within the temperature region of 50-150°C. [3]

To achieve the potential of the furan-functionalised PK to be a flexible nanocomposite, undamaged multi-walled carbon nanotubes (MWCNTs) are implemented in these polymers. MWCNTs are special form of multiple single-walled carbon nanotubes that are nested inside one another. The nanotubes in cross-linked polymers exhibit exceptional thermal, electrical and mechanical properties like mechanical strength, stability at elevated temperatures and reliable electric performance. On the other hand, cross-linked polymer nanocomposites are not recyclable nowadays, which can be changed with the thermal reversible moieties. Thermoplastics like PK are attractive in supporting materials for MWCNTs because they're easily fabricated into different solid state forms. Even though the carbon nanotubes are semi-conductors, plastic polymers often require stable electric response for a wide range of temperature differences. Next to electrical response, the thermoset polymer should be fit for external mechanical forces and chemical stress as well as thermal stress. The most important property is to preserve the electrical properties of the carbon nanotubes. Polycyclic aromatic groups will, because of their structure, interact with the graphite composition of the tubes. Furan-functionalised polyketone (PK-Fu) becomes electrically conductive through addition of moderate amounts of MWCNTs. With the addition of MWCNTs intrinsic self-healing can be promoted by thermally reversible Diels-Alder crosslinks activated by resistive heating. Also, MWCNTs contribute in the reversible crosslinking of the PK-Fu with B-Ma due to the diene/dienophile character of the MWCNTs and their increased graphitic order after network formation. [4]

Although this all seems very nice, the excess of hydrophilic moieties in the polymer over aromatic groups lead in a lack of stabilization in nanoparticles. This should be solved. Stability can be enhanced when the amphiphilic character is increased. Next to the furfurylamine another component can be added to the main chain, showing both the low linear aromatic density and low linear charged density. This is possible with reacting Pamba to the PK. The ratio in Pamba and furfurylamine in the PK will have effect on the thermomechanical re-workability, stable electrical response and resistivity in heating, and the behaviour of recycling the polymer. The furan moieties allow thermal setting of the polymer by the DA and retro-DA sequence with B-Ma, while amine moieties allow tuning the hydrogen bonding density. By this combined approach, it is possible to synthesize well-defined thermosets with a wider glass transition temperatures (Tg) window with respect to PK-FA alone. [5]

Spectroscopic tools will be used to study the modification and crosslinking of the polyketones as well as the thermoreversibility of chemical bonds with the nanotubes. Results concerning the mechanical performance and electrical performances of the polymer will be analysed and show the overall performance of the PK with the functionalized moieties.

## Materials & Methods

### Materials

The alternating aliphatic polyketone (PK) is a co- and terpolymer of carbon monoxide with an olefin content of 30% of ethylene and 70% of propylene (PK30, MW 2140 Da). Furfurylamine (Fu, Sigma Aldrich, ≥99%, Zwijndrecht, The Netherlands) was freshly distilled before use, and 4-aminomethyl benzoic acid (PAMBA) (Sigma Aldrich, MW 151.16 g/mol, 97%), 1-propanol (Sigma Aldrich), MWCNTs (O.D. 6-9 nm, average length 5 μm, Sigma Aldrich 95% carbon), DMSO-D, 1,1-(methylenedi-4,1-phenylene)bis-maleimide (B-Ma, Sigma Aldrich 95%), deuterated chloroform (CDCl<sub>3</sub>, Sigma Aldrich 99.8 atom% D), and chloroform (CHCl<sub>3</sub>, Laboratory-Scan, 99.5%) were purchased and received.

### Procedure

The reaction between the PK and furfurylamine/PAMBA is carried out via a Paal-Knorr reaction, and the molar ratio between the reactant and the PK was established with a maximum conversion of 80% according to Zhang and Toncelli [6][7]. The exact ratio PK-Fu-Pamba was set on 20%-60%-20%. In a flask 4.82g PAMBA (0.032 mol) is dissolved into 100mL 1-propanol and is stirred for 24 hours at 100°C. Next to this, 21.00 g of PK is stirred at 620 rpm at 110°C and furfurylamine is added drop wise. After 4 hours the stirring is stopped and 50mL of 1-propanol is added before the PAMBA solution is put in to the PK solution. The combined solution is refluxed at 100°C and 700 rpm. After refluxing the reaction for 24 hours it is stopped, chloroform was added to dissolve and remove the polymer from the flask. After blowing out most of the solvent, the polymer was dried for 48 hours in the vacuum oven at 50°C. After washing and drying (48 hours in the oven) of the polymer, PK-Fu-Pamba is characterized.

The carbonyl conversion ( $C_{CO}$ ) of PK can be calculated with multiple formulas:

$$C_{CO} = \frac{y}{x + y} * 100 \quad (1)$$

Where x is the amount of moles of the dicarbonyl unit and y the amount of moles of the pyrrolic unit. The y can be calculated with:

$$y = \frac{N}{M_n} \quad (2)$$

With N being the weight of nitrogen in the final product, as determined with the elemental analysis and  $M_n$  is the atomic weight of nitrogen. The value x can be calculated with:

$$x = \frac{\frac{C}{M_C} - y - n_y^C}{n_x^C} \quad (3)$$

With C being the weight of the carbon in the final product measured with the elemental analysis.  $M_C$  is the atomic weight of the carbon and the  $n_y^C$  and  $n_x^C$  are the average number of carbons of both the pyrrolic and carbonyl part. The conversion efficiency ( $\eta$ ) could then be calculated with:

$$\eta = \frac{y}{mol_{Fa}} * 100 \quad (4)$$

With  $mol_{Fa}$  being the moles of furfurylamine at the start.

PK-Fu-Pamba (2.0g) was collected and added with 0.297g B-Ma (ratio Fu/B-ma 1:1) and the MWCNTs in six different ratios. The six amounts of MWCNTs are 0.0%, 0.1%, 0.5%, 1.5%, 2.5% and 5.0% of the

PK-Fu-Pamba mass, dissolved in chloroform (1g/10g) and sonicated for half hour. The reaction is stirred at 50°C for 24 hours in an oil bath using a temperature controller to regulate the temperature inside the flask. After the reaction was stopped, the solvent was removed in vacuum oven at 60°C for 48 hours. The resulting powder was divided into different portions of 500mg and moulded in rectangular bars at 150°C for 30 min at 40 bar. After the moulding, the samples were cooled down and stored at -17°C for further analysis.

#### *Base analysis*

Also a baseline with 80% conversion of Pamba with PK-30 is done. For this the exact ratio PK-Pamba was set on 20%/80%. This means that 4.82g (0.032 mol) Pamba was mixed for 24 hours with 1-propanol, where after the solution is reacted with 5.43g PK-30. After the reaction the mixture is dried for 24 hours in the vacuum oven at 50°C. After washing and drying (48 hours in the oven) of the polymer, PK-Pamba was characterized.

#### *Characterisation*

$^1\text{H}$  NMR spectra were recorded on a Varian Mercury Plus 400 MHz apparatus using deuterated chloroform as solvent. FT-IR measurements were done with a Perkin-Elmer Spectrum 2000. An Elemental analyses was done in a Euro EA elemental analyser. Differential Scanning Calorimetry (DSC) analysis was performed on a TA-Instrument DSC 2920 (Eschborn, Germany) under N<sub>2</sub> atmosphere. The samples were weighed (10-17 mg) in an aluminium pan to see if there are any side reactions, which was sealed afterwards. The samples were then heated from 40°C to 180°C and cooled down back again. The heat-cooling cycles were done with a rate of 10°C/min. Gel Permeation Chromatography (GPC) measurements were performed with a HP1100 Hewlett-Packard. The equipment consists of three 300 × 7.5mm PLgel 3  $\mu\text{m}$  MIXED-E columns in series and a GBC LC 1240 RI detector. The polymer samples were dissolved in THF (1 mg/mL) and eluted at a flowrate of 1mL/min and a pressure of 100-140 bar and temperature at 40°C.

#### **Results & Discussion**

The reaction of Furan and Pamba with polyketone is done via a Paal-Knorr reaction. This is a synthesis of amphiphilic copolymers. The amine of the furan or Pamba attacks the other carbonyl to form a pyrrole derivative which undergoes dehydration to give the corresponding pyrrole.

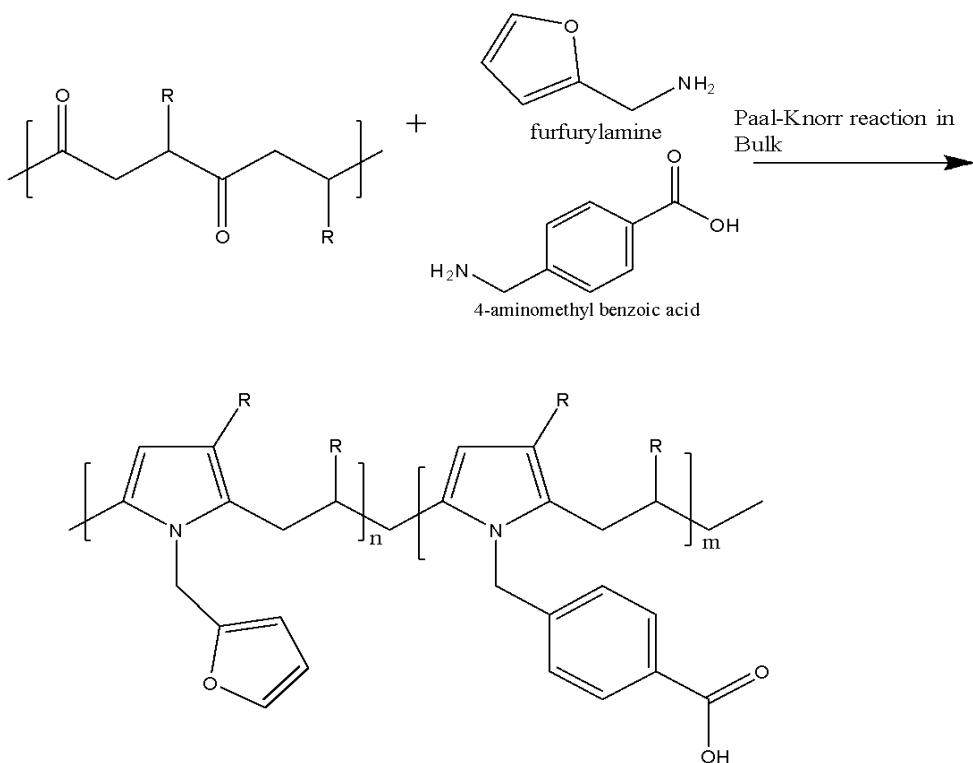


Figure 1: Schematic representation of PK functionalised with furan and Pamba groups

After this MWCNTs was reacted with the Pk30-Fu60-Pamba20 and b-Ma to crosslink the polymer. With this the composite is functionalised. After the reaction the polymer is washed with THF so all the non-reacted components are removed and the purified functionalised polymers are moulded into bars to do tests on and study it.

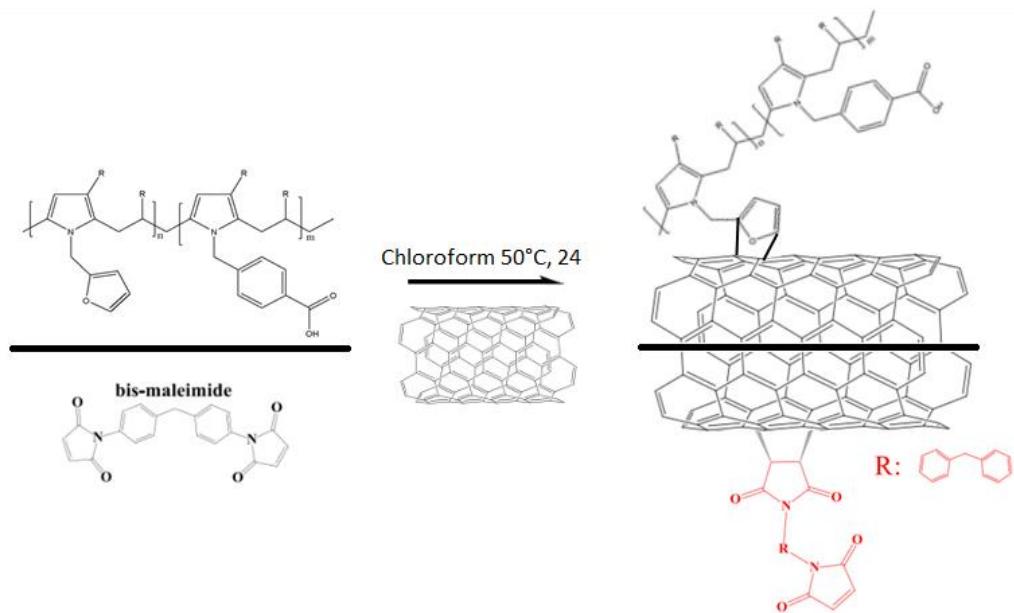


Figure 2: Functionalisation of MWCNTs with PK-Fu-Pamba (diene) and bis-maleimide (dienophile)

### *Conversion*

The elemental analyses gives the weight percentage of the three components in the polymer. The results are given in the table. Also, the total carbonyl conversion is calculated.

Component	N(%)	C(%)	H(%)	Xco(%)	$\eta$ (%)
PK30-Pamba20-Furan60	5.37	71.06	7.09	70	87
PK30-Pamba80	4.02	68.39	6.97	73	92

**Table 1: Experimental results of PK30-Fu60-Pamba20**

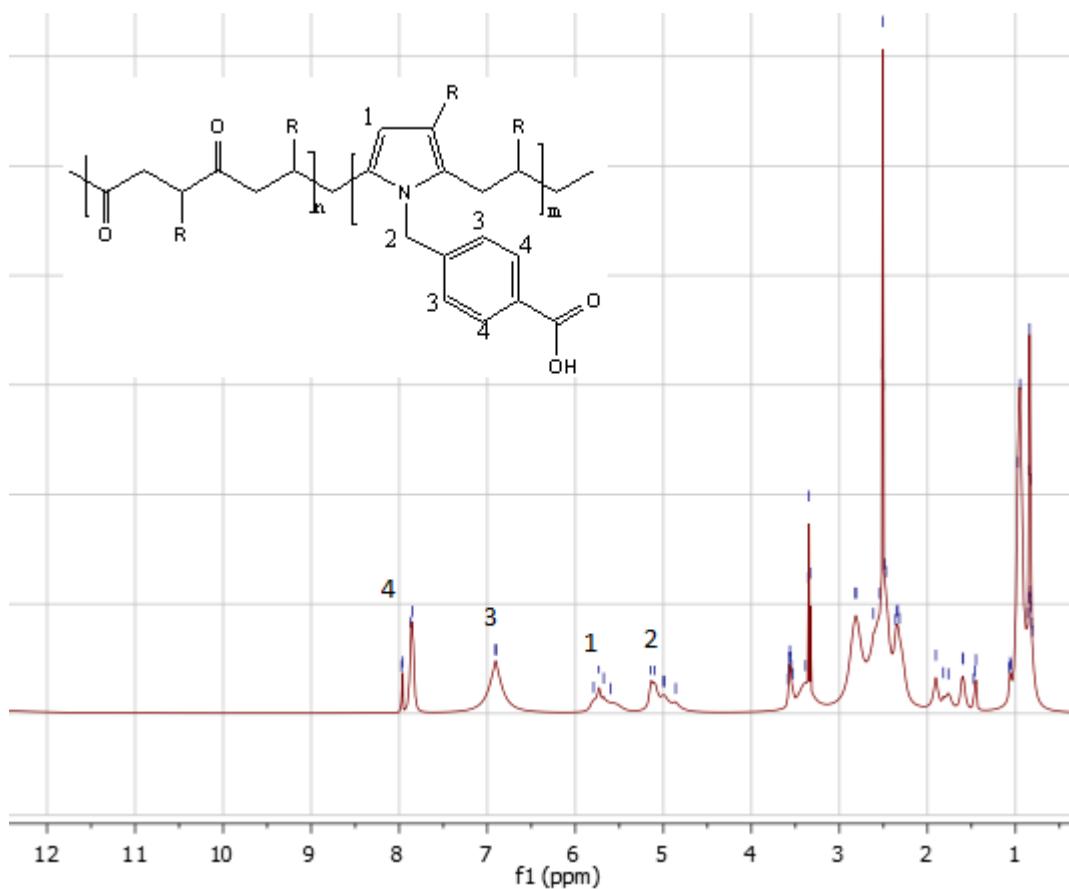
The conversion of both samples is around the 90% efficiency. The reaction should therefore have to be somewhat longer in time to perhaps get a higher conversion. Still comparing to average reactions with Pk30-Fu80 or other reactions, this conversion rate isn't that low. Pk30-Fu80 got a efficiency of 92% in the paper of Araya in 2018 with almost the same procedure. [4] Therefore the conversion is sufficient.

### *Characterization*

#### **H-NMR peaks**

Spectral characterisation is done for the Pk-Fu-Pamba and Pk-Pamba with H-NMR and FT-IR. Both are analysed by studying specific functionalities that are correlating to functional groups of the functionalised polyketones.

The H-NMR in Figure 3 is showing a proton signal (proton 1) that is correlating to the pyrrole ring and is displayed in the spectrum between 5.5 and 6.0 ppm. The protons of the carbon between the amine and benzoic acid have signals around 5 ppm (protons 2). The protons of the benzoic acid group are displayed between 7 and 8 ppm (protons 3 and 4).[8]



**Figure 3:**  $^1\text{H}$ -NMR spectrum of PK30-Pamba80

As it already was with the PK30-Pamba80, the PK30-Furan80 is also showing the presence of pyrrole group with peaks between 5.5 and 6.0 ppm (proton 2). The peaks that can be seen between 4.5 and 5.0 ppm are the protons of the  $\text{CH}_2$ -group between the pyrrole and the furan (proton 1). The protons of the furan are more deshielded and are the three peaks between 5.5 and 7.5 ppm (protons 3, 4 and 5).[5]

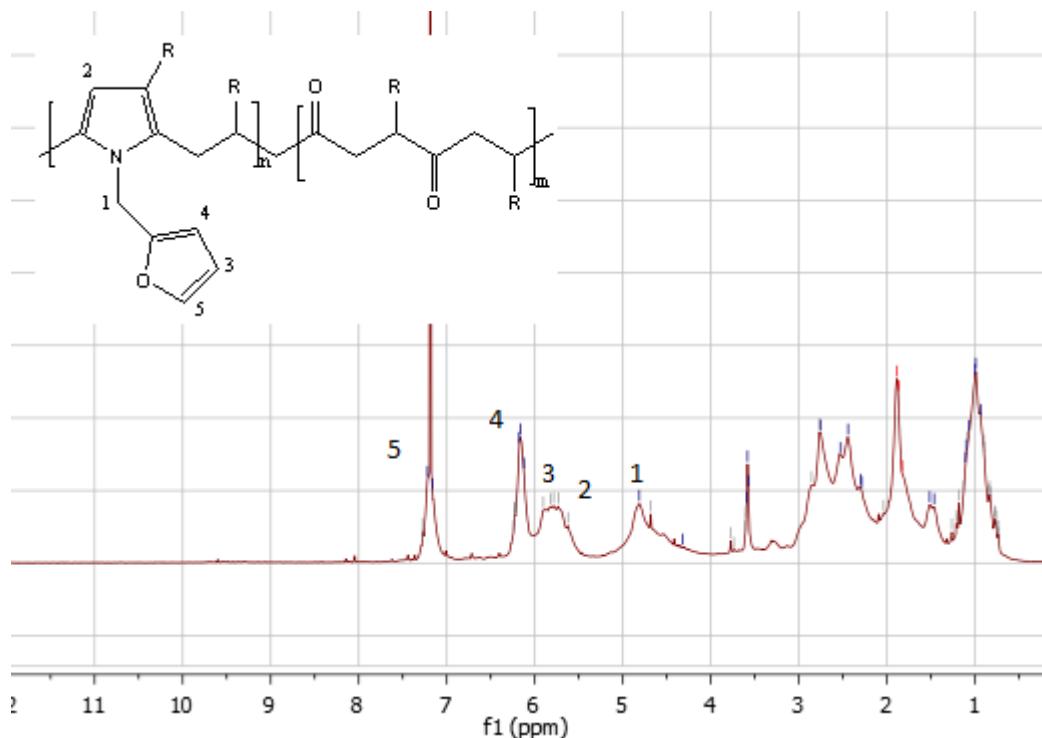
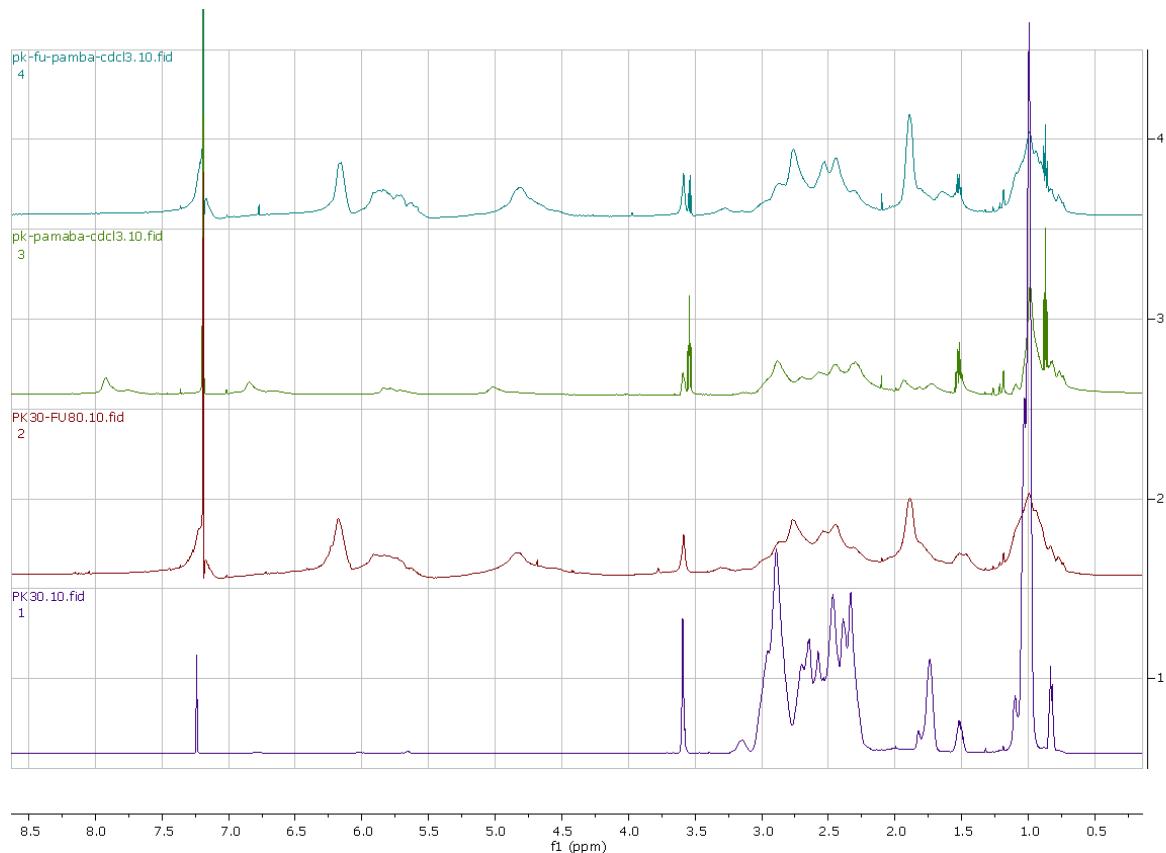


Figure 4: H-NMR spectrum of Pk30-Fu80

Also H-NMR analysis was done with PK30, PK30-FU80 and PK30-Pamba80 and compared with the furan60/Pamba20 functionalised polyketone. The spectrum for the polymer system is showing much presence of furan in the system, because of the similar peaks between 5.5 and 6.0 ppm. Also it has decreased the peaks around 3.0 and 2.5 ppm compared to Pk30, which can be linked to the reaction of ketones and the disappearance in that case. Both Pk30-Pamba80 and Pk30-Fu60-Pamba60 are showing the same multiplets at 3.6, 1.5 and 0.9 ppm, but none gives inclusion of a lot of Pamba reacted with the polyketone, because important peaks discussed earlier in this paper with the peaks between 7 and 8 ppm are for example are not visible in the spectrum. Furthermore, Pamba is not soluble in chloroform and no undissolved solids were observed. [9] Therefore, the unknown multiplets couldn't be unreacted Pamba. On the other hand, the peaks are at 0.9, 1.6 and 3.5 ppm, which is matching with the H-NMR peaks of 1-propanol.[10] This was used as solvent for the Pamba and most likely still in the polymer. This means it is not clear if the estimated complete amount of Pamba has fully reacted with the polyketone, but for sure is that much furan has been reacted to the PK.



**Figure 5: H-NMR spectra of 1. Pk30, 2. Pk30-FU80, 3. Pk30-Pamba80, 4. Pk30-Fu60-Pamba20**

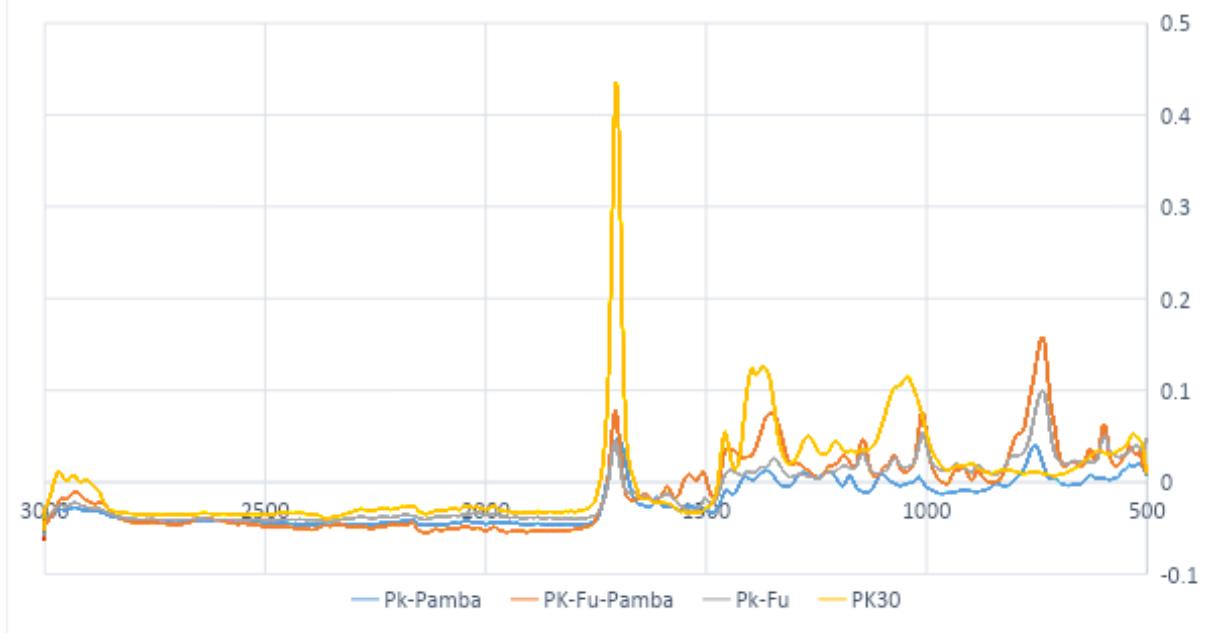
#### Fourier-Infrared

The FT-IR spectrum of the same samples is displayed in figure 6. The signal in the IR of carbonyl stretching is in every compound present although the 1,4-carbonyl moieties are converted to pyrrole rings with the Paal-Knorr reaction, because of the much lower intensity of that stretch compared to Pk30. This means that indeed not all ketones have reacted into pyrrole rings, but comparing this peak with unreacted shell it seems a lot of the ketones have been replaced by other moieties. The peak corresponding to the out-of-plane C-H bending of the benzoic and furan groups ( $\sim 750 \text{ cm}^{-1}$ ) appears after reaction with the Furan and Pamba. This could also be a 1' or 2' amine N-H stretch.

To clearly see the presence of both the moieties in the polymer, the IR is further investigated in the fingerprint area.

At  $1100 \text{ cm}^{-1}$  a stretch is seen for PK-Fu-Pamba and Pk-Fu which corresponds to Ester C-O stretch of a furan.

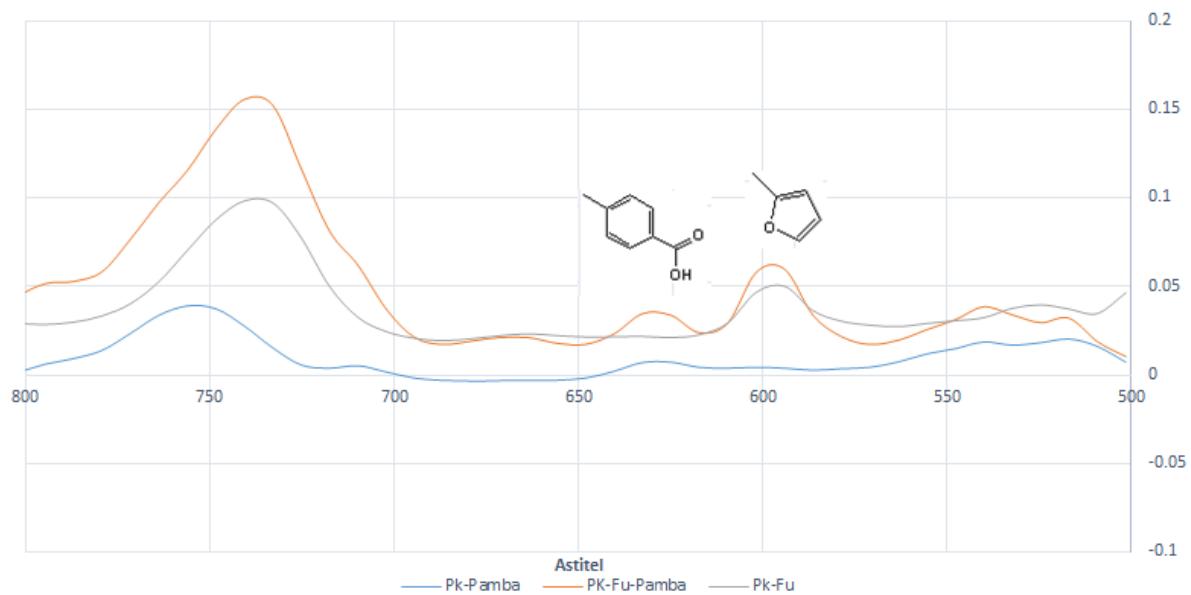
## Non-crosslinked polymers



**Figure 6:** The FT-IR Spectrum of Pk30-Pamba80, PK30-Fu60-Pamba20, Pk30-Fu80 & Pk30

Another part of the fingerprint is shown in figure 7. The FT-IR spectrum in the region of 700-500 cm<sup>-1</sup> displays the magnification in the C-H bending region (furan peak 590 cm<sup>-1</sup> and benzoic acid peak 630 cm<sup>-1</sup>). It is not really clear if the spectrum displays the presence of both groups or that it is maybe a side reaction which occurred, still both have an unique stretch that also has been observed in one of the Pk-Pamba or Pk-Fu. Peaks of Pk-Fu-Pamba that matching peaks of PK-Pamba are almost impossible to see, because of the small peaks of the Pk-Pamba

## Non-crosslinked polymers



**Figure 7:** FT-IR spectrum of the fingerprint region

As can be concluded, no Pamba has reacted with the polyketone and therefore only Pk30-Fu60 is observed. This means that further study about the polymer is done for this composition instead of the polymer composite with Pamba.

### GPC

The polyketone had before the reaction an Mw of 2140 Da. After the reaction this value should change. The GPC result of the Pk30-Fu60-Pamba20 gives a Mw of 6230 Da. This value is 3 times as high as the pure polyketone. For the Pk30-Pamba the GPC shows a Mw of 1940 Da. This is smaller than the pure polyketone.

Sample	Mn (Da)	Mw (Da)	PDI
Pk30-Fu60-Pamba20	2110	6230	3.0
Pk30-Pamba80	902	1980	2.2

Table 2: The experimental results of the GPC for Pk30-Fu60-Pamba20 & Pk30-Pamba80

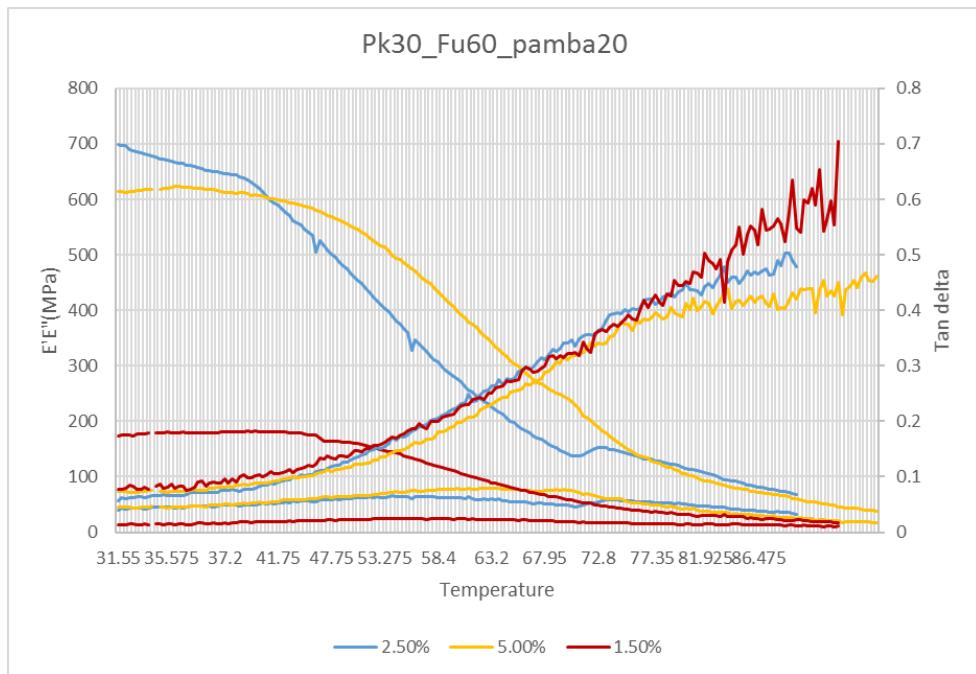
The PDI of the two systems are really different. The polymer with furan has a high PDI number which is unlikely. This means that there is a high distribution of molecular mass in the system.

### DMA

The thermo mechanical features of the cross-linked polymer were determined with the DMTA analysis. It was performed on the rectangular bars. For all different bars containing other weight percentages of MWCNTs the softening point ( $\tan \delta$ ), loss and storage moduli were determined at different temperatures.

For the 5.0%, 2.5% and 1.5% all the three measurements are given in figure 8. As can be seen from the graph the contents with more carbon nanotubes have much higher moduli, but the  $\tan \delta$  is not changing much, almost even neglectable.

The storage and loss modulus are increasing with addition of more carbon nanotubes into the polymer, until it reaches the 2.5% of CNT in the bars. The values of both the storage and loss modulus are higher for bars with 2.5% than for 5.0% at low temperatures. On the other hand, around 40°C the bar with 2.5% CNT crosses the 5.0% and has lower moduli. This can maybe explained by the re-DA that is starting after this temperature and the decrosslinking occurs. The bars will be more dependent on the strength of the carbon nanotubes. The moduli are very different due to addition of a small amount of CNT, still it doesn't have much effect on the softening point of the bars. The specific temperature of the softening point is hard to see due to the variable ups and downs in the trend.



**Figure 8: DMTA of PK-Fu-Pamba cross-linked with b-Ma and reinforced with 5 wt%, 2.5 wt% & 1.5 wt% MWCNTs**

In a paper of Araya it was shown that PK30-Fu80 functionalized with CNT's was self-healing. Also here a DMA analysis was done. The storage modulus was for this composition higher and had a higher softening point than the polyketone also functionalized with Pamba. The softening point of Pk30-Fu80 had a softening point of ~140°C, where the Pk30-Fu60 doesn't even goes above 90°C. [4]

#### DSC

The glass transition temperature was determined with the DSC. For the PK30-Fu60 this was measured together with the cross-linked polymers reacted with the carbon nanotubes. In literature of Araya the Tg 30°C.[3] The Tg measured by the DSC for the Pk30-Fu60 in this study was almost 40°C. Also, expected was that the pyrrole groups increase the rigidity of the backbone.[4] And this increase was seen.

Samples	Tg (°C)
PK30-Fu60-Pamba20	39.4
PK30-Fu60-Pamba20-5.0%	66.0
PK30-Fu60-Pamba20-2.5%	66.5
PK30-Fu60-Pamba20-1.5%	67.0

**Table 3:Tg values of polyketone 30 functionalized (PK30-Fu) non-crosslinked and crosslinked between furane and maleimide groups.**

As can be seen from the table the cross-linked polymer has a much higher Tg, as expected. Another trend that can be seen is that the Tg is increasing when less carbon nanotube is added.

Moreover, when the ratio Furan/b-Ma is set on 1/0.75 only 60% of all monomer parts can crosslink. This is comparable when only 60% of the carbonyl has converted. The Tg determined is around the 66°C, which is much lower than the Tg of 75% crosslinked Pk30-Fu60. That is 130°C.[3]

The DSC analysis of the PK-Fu-Pamba is showing one transition around 40°C and is associated with the glass transition temperature of the material.

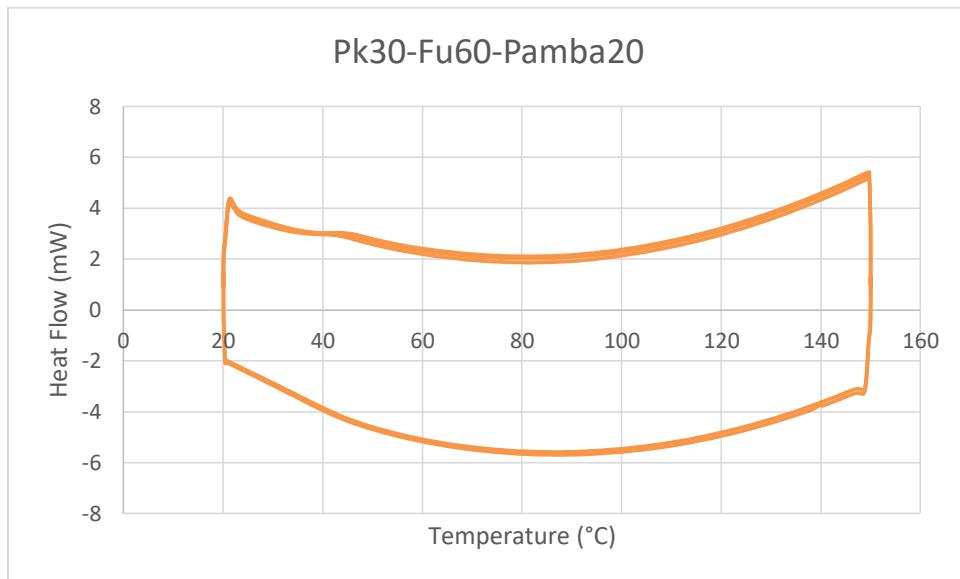


Figure 9: DSC thermal cycles of Pk30-Fu60-Pamba20

After obtaining the furan and Pamba functionalised polyketone, B-Ma was added (ratio 1:1 between Fu and Ma groups) together with different weight percentages of MWCNTs. Then, bars were made by compression moulding the reaction was finished. This gave a new cross-linked nanocomposite and was characterised by the DSC to thermal behaviour, reversibility, and the exo-/endo-thermal processes related to the DA and retro-DA sequence. The analysis displayed endothermic transition in the range around 60°C and 35°C for each thermal cycle. Therefore the MWCNTs do not interfere with the thermal behaviour.

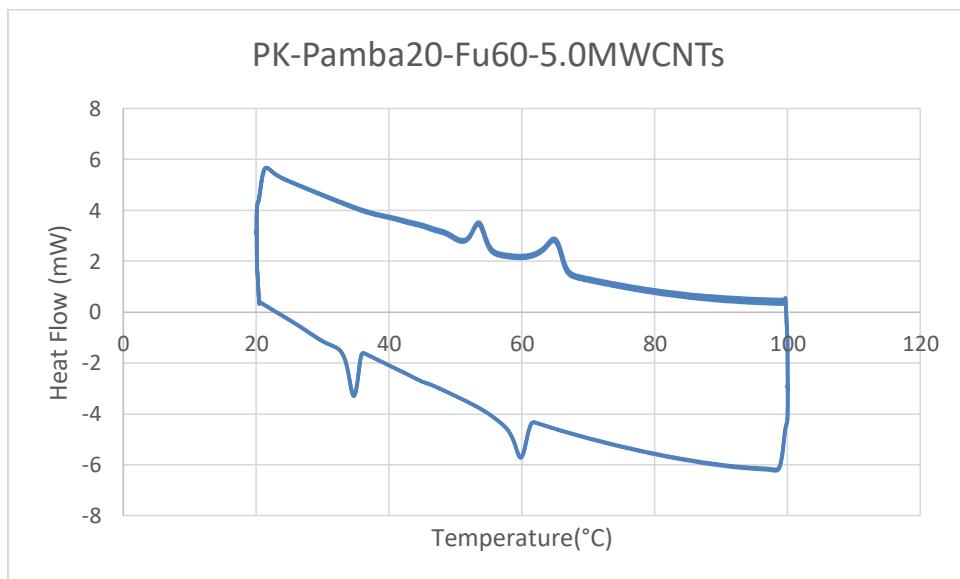


Figure 10: DSC thermal cycles of Pk30-Fu60-Pamba20 cross-linked with b-Ma and reinforced with MWCNTs

## Conductivity

To see if the nanocomposite is actually electrically conductive, bars are connected to a voltmeter and ammeter while electrical potential is applied on the bar. To get a smooth connection between the meters and decreasing the resistance between the bar and wires, silver conductive paste surrounded with a layer of aluminium foil is wrapped around the edges of the bar. With this the electrical properties of all different bars could be measured.

For the PK30-Fu60-Pamba20 with 5.0% CNT the following values were measured with the ammeter and thermometer. With these values the resistance of the bar can be calculated . The dimensions of the bar are thickness = 0.78 mm, width= 6.70 mm and a length of 13.80 mm.

Temperature (°C)	Voltage (V)	Current (A)	Conductance (S)	Electrical Conductivity (S/m)
68	13.5	0.05	0.0040	10.6
114	19.3	0.0825	0.0043	11.4

Table 4: The results of electrical properties of Pk30-Fu60-Pamba20 cross-linked with b-Ma and reinforced with 5.0 wt% MWCNTs

The conductance is going up when the temperature is increasing. This means it conducts better at higher temperatures. With the dimension of the bar the electrical conductivity ( $\sigma$ ) can be calculated.

Also other samples have been applied to an electrical tension. The functionalised polyketone bars with 0.0% and 0.1% were not conducting electricity and therefore left out in the results.

Sample	Voltage (V)	Current (A)	Conductance (S)	Electrical Conductivity (S/m)
2.5% CNT	22.7	0.243	0.011	22.7
	32.9	0.424	0.013	26.9
1.5% CNT	18.5	0.010	5.4e-4	1.66
	29.0	0.019	6.5e-4	1.99
	47.9	0.044	9.2e-4	2.81
0.5% CNT	45.9	0.8e-3	1.74e-5	0.053
	56.0	1.0e-3	1.78e-5	0.054

Table 5: Table 4: The results of electrical properties of Pk30-Fu60-Pamba20 cross-linked with b-Ma and reinforced with 0.5wt%, 1.5 wt% and 2.5 wt% MWCNTs

The electrical conductivity is going down rapidly when the amount of carbon nanotubes is decreasing. The bars with 5.0% and 2.5% couldn't go higher than the values of voltage applied shown in the table, because the bars were burning at higher values. For the 0.5% a lot of electric tension should be applied to see a small current going through the bar.

For testing the self-healing by electrical force should be done with the 5.0% CNT sample because of its high current at low electric tension.

### Thermoreversibility

With the knowledge that the bars are electrically conducting, the self-healing of the Pk-Fu-Pamba can be studied. The same setup is used as it was for the conductivity study, but now a camera is filming the bar while applying an electrical force on the bar. Also, a scratch is made on the bar to see if the bar is having a re-DA and is changing back to its original state.

After setting up, the PK30-Fu60-Pamba20 with 5.0% CNT was recorded while applying electric tension through the bar. The figures below are showing a part of bar before cutting the bar, bar with the cut and after applying a current through the polymer.

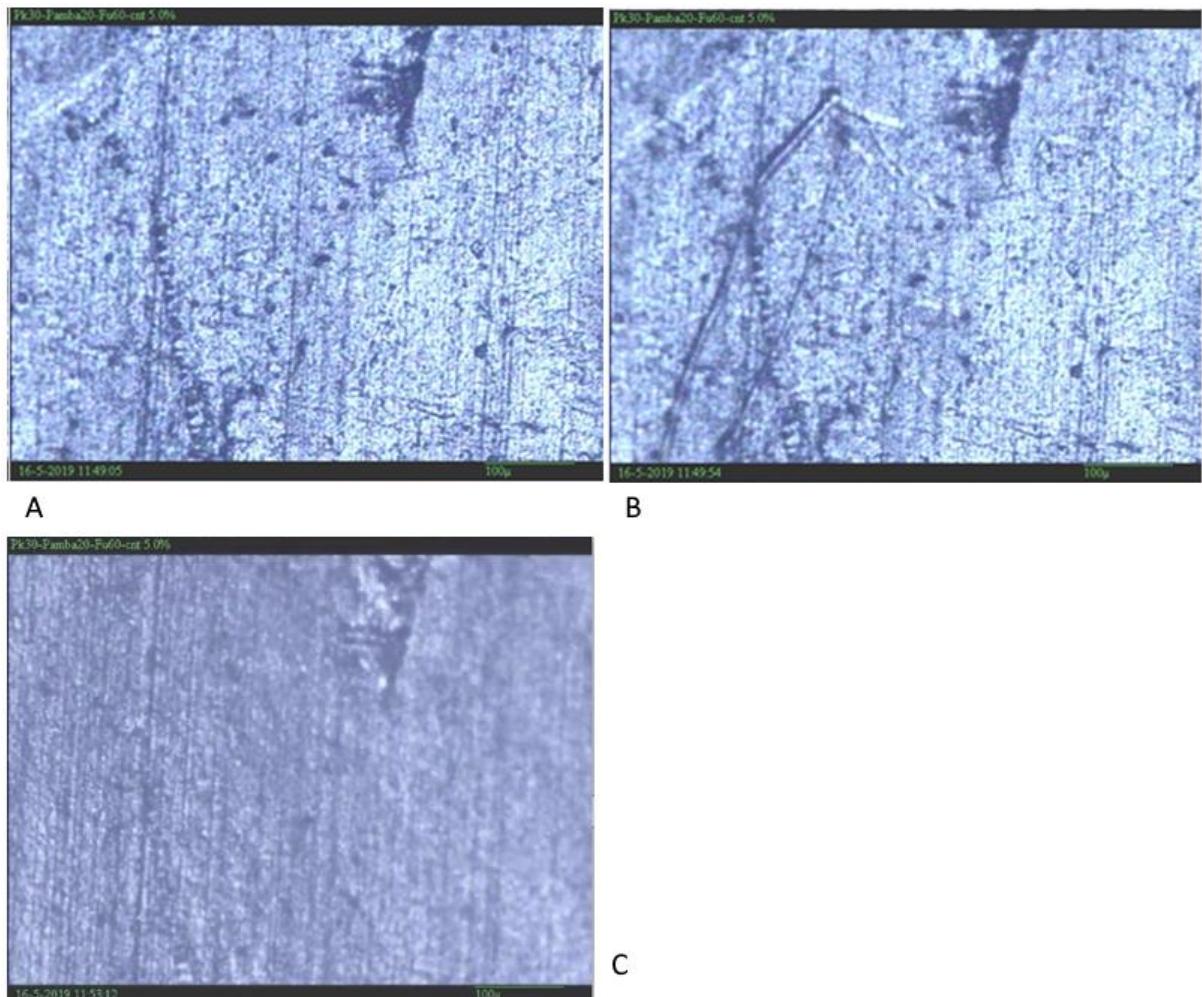


Figure 11: PK30-Fu60-Pamba cross-linked with b-Ma and reinforced with 5.0 wt% MWCNTs, <sup>A</sup> before cut, <sup>B</sup> With cut, <sup>C</sup> after applying electrical current through the bar

The pictures are showing a disappearance of the cuts in the plastic. After less than 50 seconds the whole cuts has been disappeared and is the bar restored to the original state. This shows the thermo reversibility of the polymer due electrical conductivity. The polymer is already recovering at low voltage of 13-19 V (giving a temperature of 68-120°C), which is already much lower than the electrical force needed for Pk30-Fu. [4]

## Conclusion

Already was known that furan-functionalized polyketones are becoming conductive by addition of MWCNT's and that these polyketones were self-healing. In this paper it was not succeeded to make the functionalised polyketone with Pamba. On the other hand, it was demonstrated what the influence was of a smaller amount of Furan. The study showed the properties of the polyketone with only a maximum of 60% furan conversion. The H-NMR spectra showed not clearly the presence of Pamba in the polymer, but gave multiplets which can be Pamba or side reactions. The IR-spectra also showed that a lot of ketone groups have reacted and that mostly furan and a bit of Pamba have reacted. The IR-spectra showed as well as the NMR-spectra did, that no specific peaks or stretches of Pamba could be seen. The DMA analysis showed that the storage and loss modulus are lower than for polymer with only furan moieties. The same analysis also gives low softening point around the 90°C. On the other hand does the polymer have a better electrical conductivity than the Pk30-Fu80. The main goal is evaluating the mechanical performance and self-healing ability of the composite. The DSC showed that the polymer was reworkable even after crosslinking and containing MWCNTs. After scratching the bar, it self-healed itself by putting an electrical current through it. Even at low voltage could heal the composite. The polymer is therefore a really good conductive self-healing nanocomposite.

The results are showing a brittle composite which is easy to heal, but has really low softening point and low moduli. This means the practical use of this composition is small, because of its low mechanical characteristics. Still the utility of adding Pamba can be looked again, because of the fact no Pamba really reacted. The Pk30-Fu60 has on the otherhand great electrical properties, but does not reach the high Tg values as the Pk30-Fu80 did.

## Literature

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