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Interreg North-West Europe HI-ECOWIRE
European Regional Development Fund

Technical sheet on polymer extrusion for magnet wire

Introduction to high performance polymers

In recent years, the industrial and technological rise of our societies has led to the development of new materials with specific qualities and increased resistance, in order to meet our needs and goals. More than single-used objects or future waste, polymers fully take part into progress. They have been able to prove themselves to be indispensable in so many areas that *a priori* nothing links, such as health, transport, electronics or even aerospace.

The fact is, alongside the "low-value" plastics used in everyday life, as well as all those belonging to the group of bioplastics, there is a class of polymers in its own, called "high performance", which shows singular properties. They present high thermomechanical behaviour, chemical and electrical resistance and non-toxic smokes when burnt. For example, where conventional polymers do not withstand excessively high working temperatures, high performance polymers are stable up to 250 °C (continuously).

In November 1978, the PEEK, for polyetheretherketone (figure 1) was invented by Victrex ©. It is a beige-colored polymer that belongs to the PAEK family (for polyaryletherketone). It was quickly a success in number of industrial applications requiring sealing, mechanical strength and thermal resistance (typically like joints).

Today, PEEK is also used in 3D printing or biomedical field (like implants, due to its biocompatibility). It is chemical resistant and does not melt before 340 °C[1]. It is one of the most expensive high-performance polymer on the market.

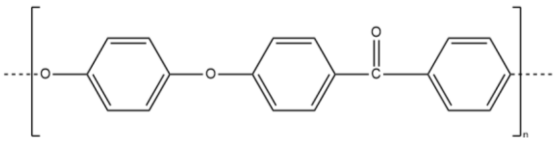

Figure 1: chemical structure of polyetheretherketone (PEEK)

PEI, for polyetherimide (figure 2), is another high-performance polymer. As the PEEK, it offers a high chemical, mechanical and thermal resistance. In addition, PEI presents adhesive properties, that can be used as beds for fused deposition modelling. Furthermore, PEI can be printed in 3D as well.

As it is amorphous, it has no melting point but a glass transition temperature about 215-225 °C and must be processed at around 360 °C. It is sold under the commercial name of Ultem © by Sabic ©.

[1] Victrex PEEK 450G datasheet. Online: https://www.victrex.com/~/media/datasheets/victrex_tds_450g.pdf

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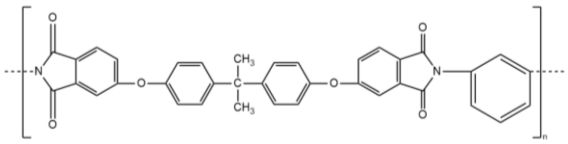

Figure 2: chemical structure of polyetherimide (PEI)

The polyphenylenesulfide (PPS – figure 3) is an amber-colored high-performance polymer on the market since 1973, under the name of Ryton © by Philipps Petroleum ©. It is semi-cristalline, melts at 285°C and can be extruded in fibers thanks to its fluidity at processing temperature (minimum 315 °C to avoid high pressure). Moreover, this property allows it to be manufactured in complex shaped pieces.

Chemical resistant, this polymer has applications in corrosive environment but has poor resistance to UV light. Though, it can be blend with another high-performance polymer (PPSU or PEI) to lead to new properties.

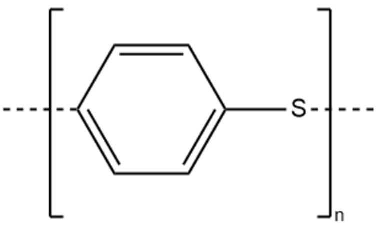

Figure 3: chemical structure of polyphenylenesulfide (PPS)

PPSU or polyphenylsulfone (figure 4) is an expensive transparent amorphous thermoplastic with high performance properties. Its glass transition temperature is around 220 °C and it shows a high hydrolytic resistance.

Moreover, studies show that PPSU can be blended with PPS to increase thermal

stability of PPS[2] and to decrease PPSU global price. It is commercialized by Mitsubishi Chemicals © under the name of Sultron ©[3].

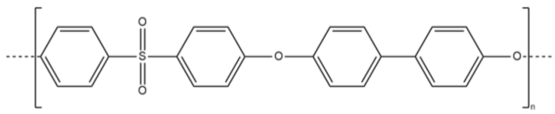

Figure 4: chemical structure of polyphenylsulfone (PPSU)

High performance polymers in Hi-Ecowire

The Hi-Ecowire project concerns coils insulation. When a current flows through the copper or aluminium filaments that make up the coils, a magnetic field is produced and used as a motive force. The filaments must be isolated from each other in order to be wound, tightened on themselves without loss of current (if insulation faults, this will lead to malfunction and danger for the equipment and the users).

To do so, the wires are currently coated with a polymeric layer . This layer is applied with an enamelling process which currently uses and releases high amounts of solvent. Hi-ECOWIRE aims at developing environmental-friendly coating alternative based on the combination of a high thermal resistant polymeric layer (using extrusion process) and a primer (based on sol-gel) to ensure high adhesion on copper wire.

[2] Journal polymère – Nouvelles 2020. « *Effets de la miscibilité partielle sur la structure et les propriétés de nouveaux mélanges hautes performances composés de poly (sulfure de p-phénylène) et de poly (phénylsulfone)* ». Online: https://fr.intermediapub.com/effects-partial-miscibility-structure-581653#menu-9

[3] Mitsubishi chemicals advance materials. Online: https://www.mcam.com/en/products/engineering-plastics/advanced-160-220/sultrontm-ppsu/?r=1

High performance polymers compounding

Although very resistant, experiments are being studied to increase the performances of the extruded polymers as high temperature electrical isolation coatings for magnet wires. .

This involves, among other technical parameters, the introduction of mineral fillers, in order to shift the temperatures of interest (to increase the glass transition temperature, or the overall heat capacity), by modifying the crystallinity.

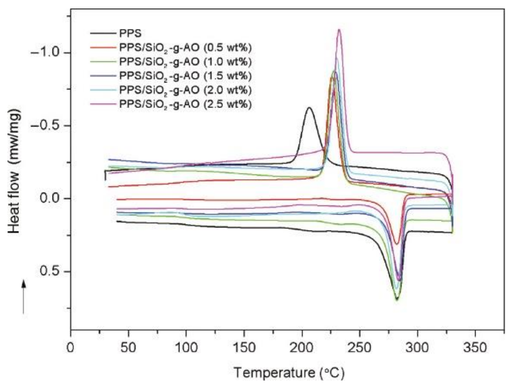

Figure 5[4]: example of PPS' temperatures transfer depending on nanofillers concentration, observed with Differential Calorimetric Scanning

These fillers are inserted into the matrix during the extrusion (figure 6). The polymer pellets are dried and milled before being blended with the mineral fillers. The mixture is put into the extruder, heated to over 300 °C (depending on the matrix). Finally, at the extruder outlet, the filament is cooled before going through the granulator where new pellets go out, ready to be shaped.

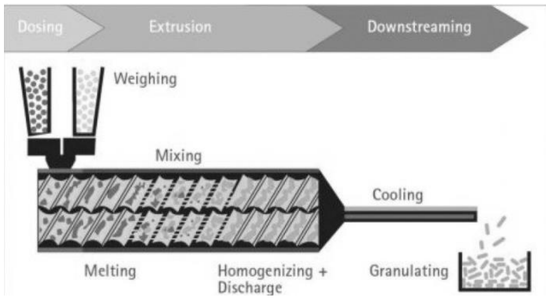

Figure 6[5]: extrusion principle with twin-screw extruder

On a laboratory scale, the equipment for the first mixing tests is a twin-screw extruder (figure 7).

Figure 7: Process 11 twin-screw extruder from ThermoFisher

The produced compounds must be injected and the moulded specimens mechanically examined (tensile and flexural tests), in order to assess whether they retain their properties.

At the same time, the Osawa method allows to check the thermal stability by estimating the degradation energy of a polymer with thermogravimetric analysis equipment. The more the polymer is stable

[4] De Gruyter. "*Preparation of nano-SiO2 compound antioxidant and its antioxidant effect on polyphenylene sulfide*". Online: https://www.degruyter.com/view/journals/polyeng/39/6/article-p556.xml?language=en

[5] ResearchGate. "*Schematic representation of twin scre extruder and processing of hot melt extrusion*". From "A review on Bioadhesive Buccal Drug Delivery Systems: Current Status of Formulation and Evaluation Methods". Online: https://www.researchgate.net/figure/Schematic-representation-of-twin-screw-extruder-and-processing-of-hot-melt-extrusion_fig4_231176666

in high temperature, the more this energy increases.

Figure 8: Plastic injection molding from Babyplast

Figure 9: Mechanical testing system

Interested in knowing more about HI-ECOWIRE project?
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