Thermoplastic nanocomposites with magnetic nanoparticles for bonding and debonding on demand applications by local induction heating

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Abstract

In this work the heating capacity of thermoplastic (TP) nanocomposite with magnetic nanoparticles (MNPs) as a function of time in a radiofrequency (RF) generator with a solenoid coil type is studied, varying the working parameters (i.e., maximum power, frequency, time) [1]. Exposure of nanocomposites to magnetic field results in temperature increase proportional to the MNPs concentration as a function of exposure time in magnetic field. High temperature increase, thus high heat capacity, cause melting of nanocomposites.

Motivation

Induction heating is a convenient and flexible method to deliver high-strength magnetic fields to ferromagnetic nanoparticles, which act as susceptors, generating heat in nanocomposite materials by hysteresis [2]. Taking advantage of the induction heating mechanism, nanocomposite materials embedded with magnetic nanoparticles (MNPs) constitute promising materials for adhesive joining systems, enabling reversible joining procedures, providing easy-to-disassembly operations by induction disassembly [3].

Nanocomposite preparation

- Twin screw extrusion system
- Nano-compounding and preparation of masterbatch (10% wt. MNPs)
- Dilutions to the desired concentration (2.5, 5, 7.5, 10 % wt. MNPs)
- Filament production with acceptable diameter of 1.75 ± 0.05 mm

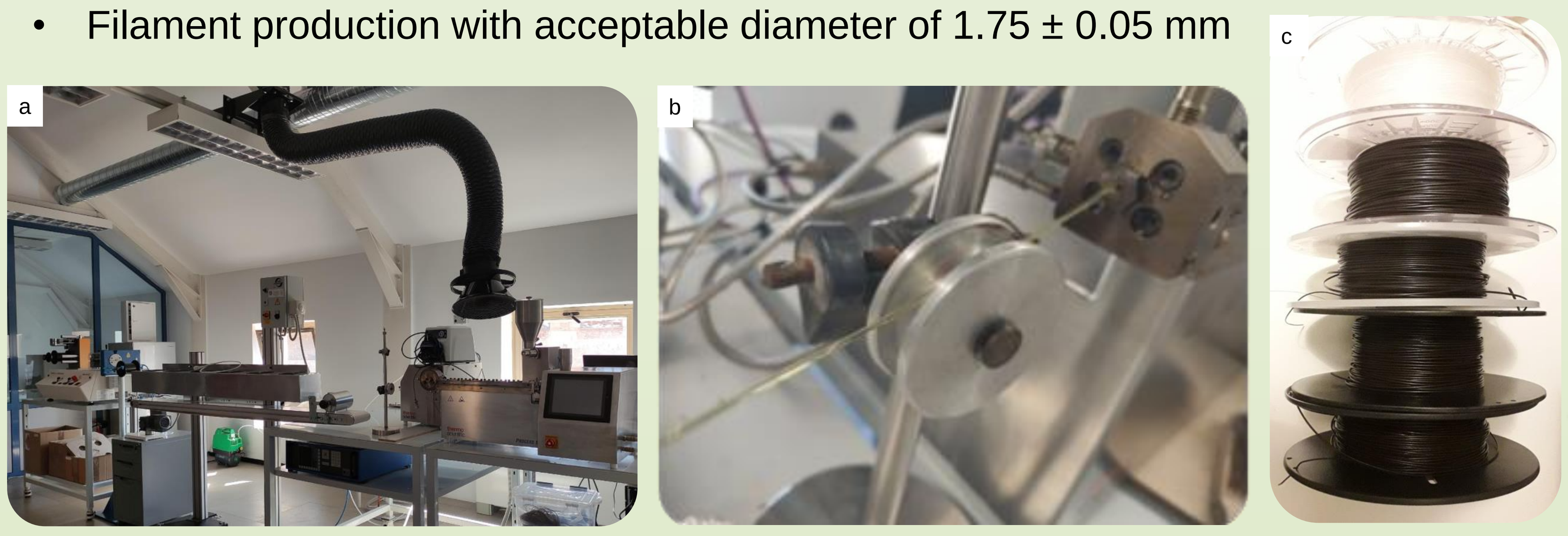


Fig 1. (a) Pilot line for nanocomposite filament development, (b) extrusion nozzle and filament roller and (c) filaments of PP with MNPs (0, 2.5, 5, 7.5, 10 % wt.).

Table 1. Extrusion process parameters

TP material	Barrel temperature	Die temperature	Screw speed (rpm)
PP	180-195	200	400
PA12	180-220	225	400
TPU	195-205	210	350
PEKK	300-310	320	400

Induction heating set up

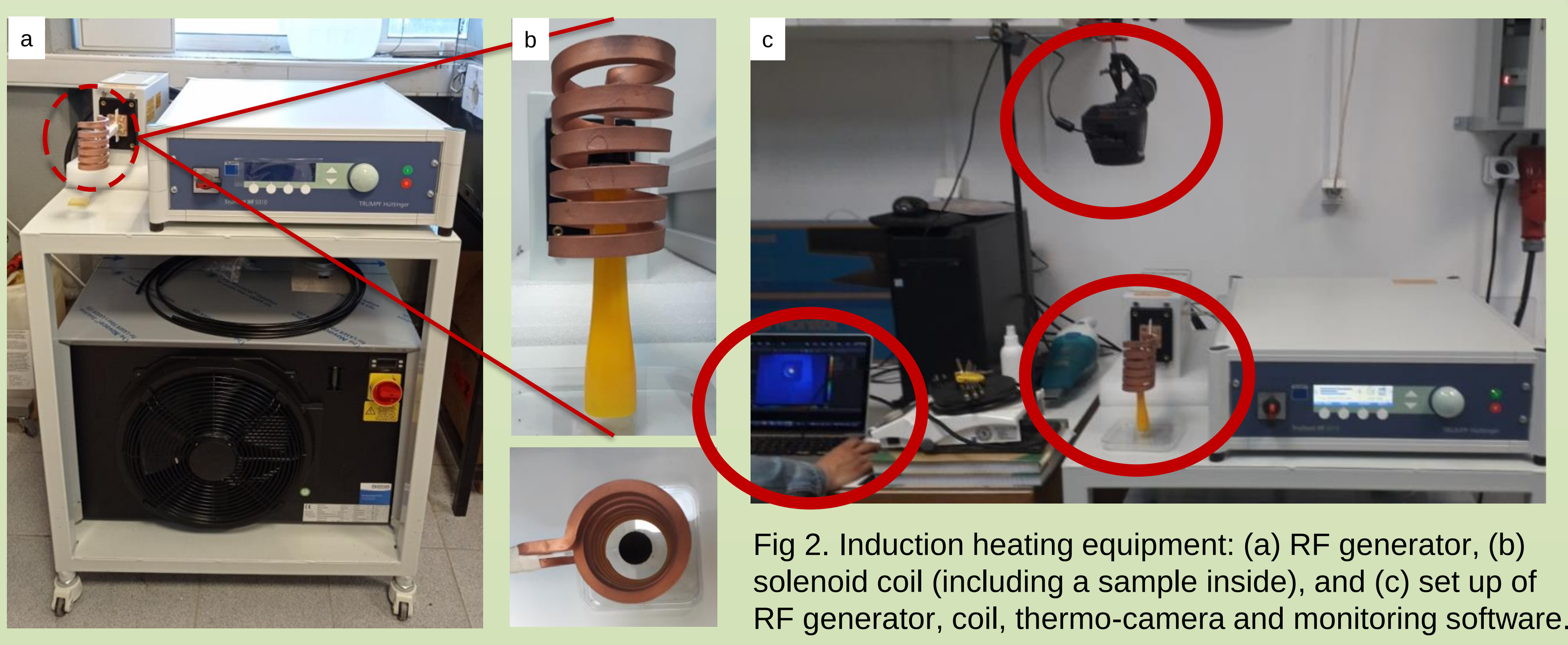
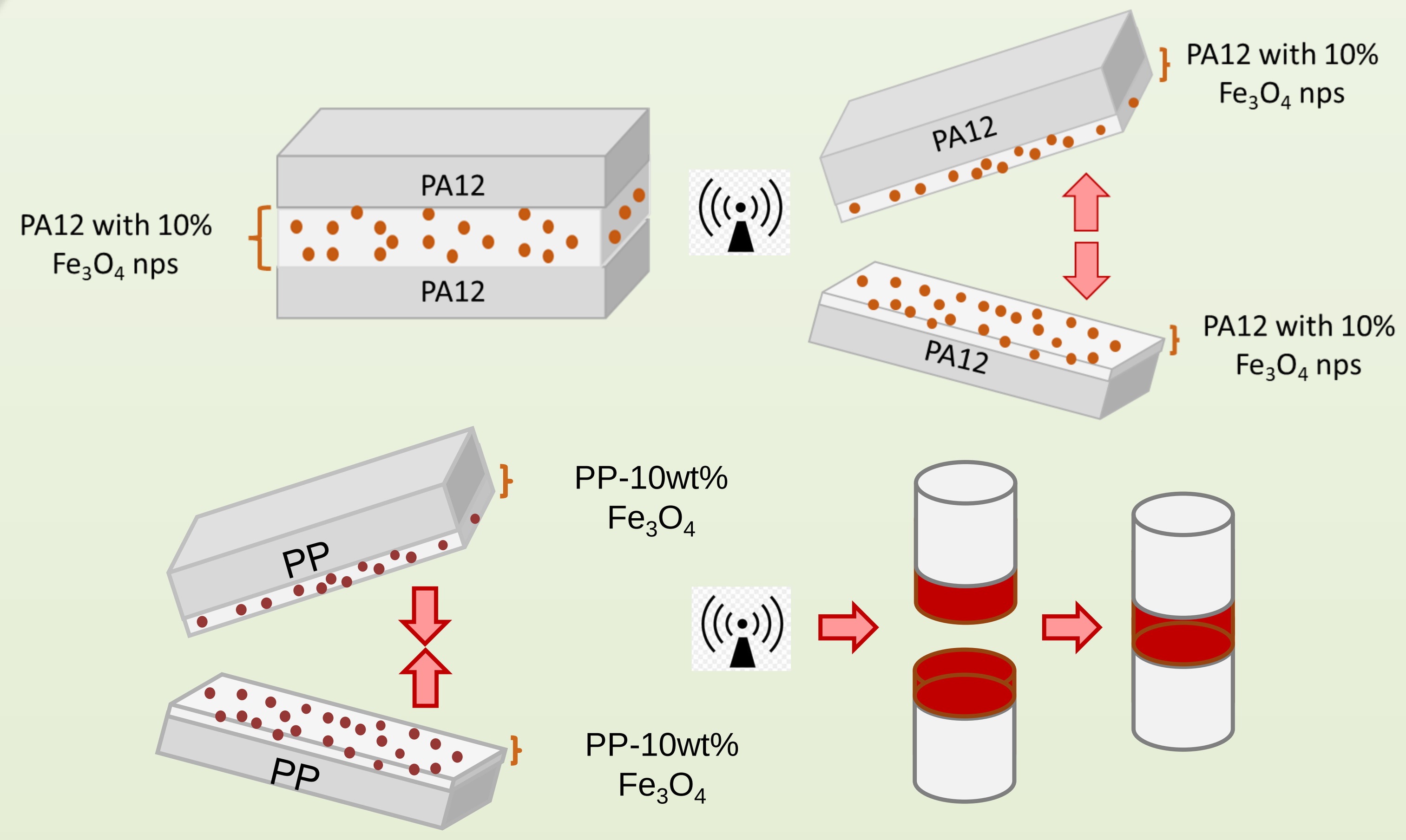


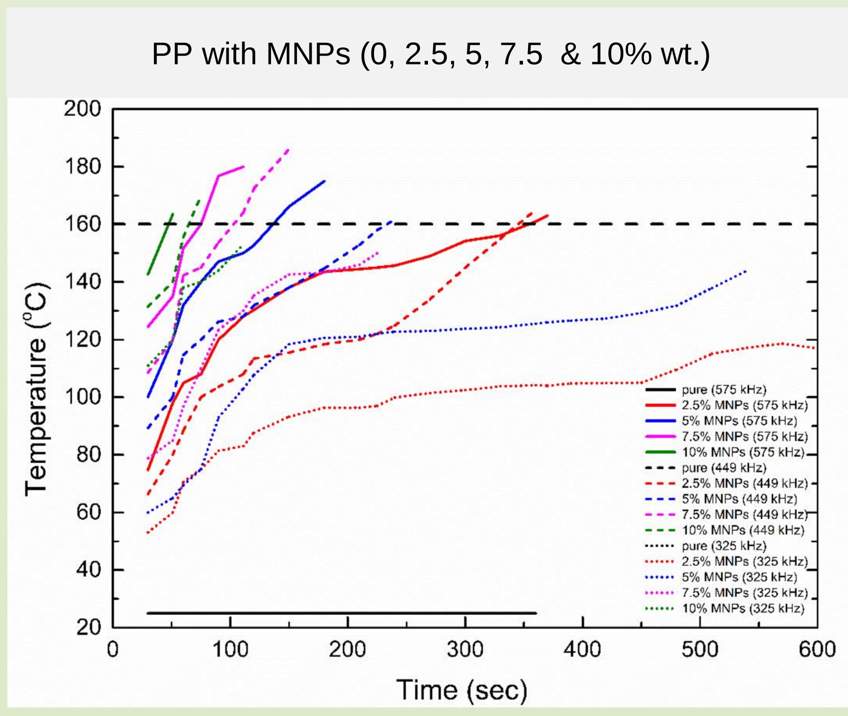
Fig 2. Induction heating equipment: (a) RF generator, (b) solenoid coil (including a sample inside), and (c) set up of RF generator, coil, thermo-camera and monitoring software.

- RF Generator TruHeat HF 5010 (max Power: 10 kW, max Current: 35 A, Input Voltage: 600 V)
- The maximum permissible RF current depends on the respective operating frequency.
- The permissible operating parameters of the currently used capacitors in the series oscillator circuit and available coil: 350 kHz, 450 kHz and 575 kHz
- Inductor coil: solenoid geometry, height = 8.5 cm and inner diameter = 4.5 cm
- Thermo-camera: Flir E5 (maximum T = 250°C) and Flir C5 (maximum T = 400°C)
- Monitoring software Flir Tools+

Bonding and debonding experiments



Heating capacity study



- Heating capacity of susceptors evaluated as a function of operating frequency
- Selection of the optimum conditions: 575 kHz and 6 kW power

Fig 3. Heating capacity of nanocomposite PP specimens as a function of exposure time in magnetic field of 575, 450 & 325 kHz operating frequency and power 6 kW.

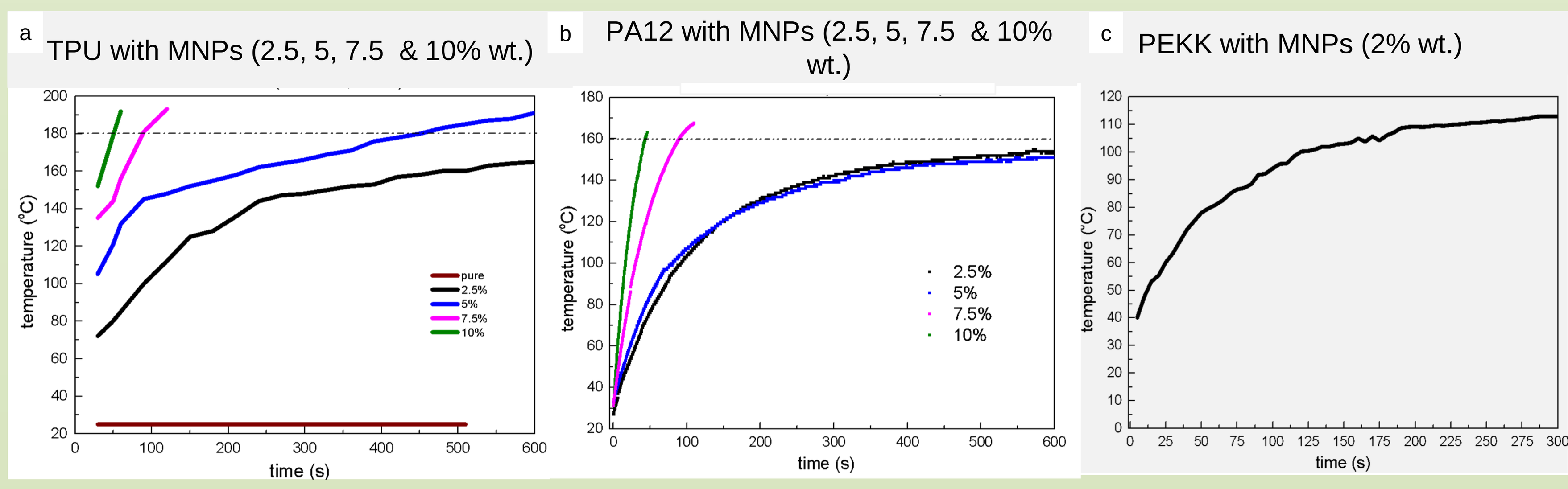


Fig 4. Heating capacity of nanocomposite (a) TPU (b) PA12 (c) PEKK specimens as a function of exposure time in magnetic field in the optimum conditions (575 kHz, 6 kW).

- Heating capacity observed in all polymer matrices embedded with MNPs
- Low concentration of MNPs requires longer time for temperature increase
- Different required time for temperature increase as a function of polymer type, MNPs concentration, operating frequency, and power

CONCLUSIONS

- Higher heating capacity in nanocomposites is achieved with higher concentration of MNPs, exposing specimens in a magnetic field of 585 kHz frequency.
- Nanocomposites of PP, TPU, and PA12 with 10% wt. MNPs reached their melting temperature in less than 2 minutes of exposure.
- Developing innovative TP nanocomposites will allow a faster and leaner integration and repair of 3D printed structures, compared to thermoset repair processes, promoting advanced applications in many fields of Nanotechnology.

ACKNOWLEDGMENTS

- 'Recycling and Repurposing of Plastic Waste for Advanced 3D Printing Applications' (Repair3D) under GA No 814588
- 'Digital method for improved manufacturing of next-generation multifunctional airframe parts' (DOMMINIO) under GA No 101007022

REFERENCES

1. M. Muddassir, "Development of nano/micro hybrid susceptor sheet for induction heating applications", Materials Science 2016.
2. I. Baek, S. Lee, A study of films incorporating magnetite nanoparticles as susceptors for induction welding of carbon fiber reinforced thermoplastic, Materials 2020, 13, 318.
3. C. Zimmerer, C. Salazar Mejia, T.Utech , K. Arnhold, A. Janke, J. Wosnitza, Inductive heating using a high-magnetic-field pulse to initiate chemical reactions to generate composite materials, Polymers 2019, 535.