Development of an Innovative Insulation Fire Resistant Façade from the Construction and Demolition Waste

DEFEAT

INTEGRATED/0918/0052

DELIVERABLE D6.2

FLOWSHEET WITH THE MATERIAL PRODUCTION

Acknowledgements

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3	28 September 2022	Marios Valanides (RECS)	RECS contribution on energy data
4	03 October 2022	Demetris Nicolaides (FRC) Michael Petrou (UCY)	Review of Deliverable
5	30 November 2022	Ioanna Giannopoulou (FRC)	Final version of Deliverable

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EXECUTIVE SUMMARY

Deliverable 6.2 presents the flowsheets for the production of the *Composite Material* developed in DEFEAT Project (Task 6.1), according to both the studied processes, casting and 3D printing. Furthermore, it includes the synthesis and curing conditions concluded for the optimized fire resistant and thermal insulation geopolymers, which are combined in the ***DEFEAT Composite Material***.

Using the Construction and Demolition Waste and in particular, the brick and ceramic tile wastes, the consortium has successfully developed compact geopolymers to be used for the passive fire protection of building (WP5, Task 5.1), as well as porous geopolymers for the thermal insulation of buildings (WP5, Task 5.2). Besides, the consortium has successfully completed the study for the compilation of these two types of geopolymers into the *DEFEAT Composite Material* (WP5, Task 5.3).

In WP6, Task 6.1, the Fire Resistant (compact) and Thermal Insulation (porous) geopolymers were optimized based on crucial properties of the geopolymeric pastes used for their production by both processes of casting and 3D printing, as well as on properties of both types of geopolymers that are critical for the final applications of the *Composite Material*.

More precisely, the viscosity and setting time of the geopolymeric pastes were evaluated so as to select the optimum Fire Resistant materials for both the production processes, casting and 3D printing. The same properties of geopolymeric pastes were also evaluated for the optimization of the Thermal Insulation materials. Furthermore, the mechanical strength (compressive and flexural) of the compact geopolymers, their density, hydraulic stability, and structural stability of at high temperatures, along with their resistance and durability in fire conditions, were evaluated in order to conclude for the optimum among the developed to be used in the *DEFEAT Composite Material*. Accordingly, the apparent density, porosity and mechanical strength were evaluated for the optimization of the thermal insulation (porous) geopolymers. The thermal conductivity of selected porous geopolymers was also evaluated so as to conclude for the optimal ones for the *DEFEAT Composite Material*. Finally, two fire resistant (compact) geopolymers (one from each waste) and four thermal insulation (porous) geopolymers (two from each waste) were selected as optimal to be combined into the DEFEAT Composite Material.

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1. Introduction

The production of the composite material developed in DEFEAT project, which is referred in this Deliverable as ***DEFEAT Composite Material***, was investigated according to the following two processes:

(i) Casting and
(ii) 3D Printing

According to the ***casting production process***, the DEFEAT Composite Materials is composed of two alkali-activated materials (geopolymers) developed and optimized in DEFEAT project: a porous material that serves as thermal insulator and a compact one that is used as fire resistant. The compact geopolymer, which is referred also as *Fire Resistant geopolymer*, is produced according to the process described in Deliverable 5.1 of DEFEAT Project for the compact geopolymers. Accordingly, the porous geopolymer, which is referred also as *Thermal Insulation geopolymer*, is produced based on the process described in the same Deleiverable 5.1 of DEFEAT Project for porous geopolymers. The combination of these two geopolymers into the DEFEAT Compact Material was investigated according to the following methods:

(a) fixing with fireproofing anchors, after hardening of the two separately produced geopolymers and

(b) bonding, by applying a thin layer of fresh geopolymeric paste prepared for the fire resistant geopolymer onto the porous surface of the hardened heat insulating material, or by casting the fresh foamed paste prepared for the Thermal Insulation geopolymer onto the surface of the casted geopolymeric paste of the Fire Resistant material (on site application).

Regarding the ***3D printing production process***, the DEFEAT Composite Material is based on the synthesis conditions of the optimized Fire Resistant (compact) geopolymers (Table 1 of this Deliverable) and is produced according to the optimum printing pattern concluded in Deliverable 5.3 of DEFEAT project. The voids existing in this printing pattern provide the material with the porosity required to reduce its thermal conductivity. Practically, the 3D printed Composite Material consists of two parts: a compact one that serves to protect the material against fire and a part with voids that is used as thermal insulator.

Effectively, the combination of a 3D printed Thermal Insulating material with targeted voids created by means of appropriate patterning on a compact casted Fire Resistant geopolymer can be the practical synthesis of the final *DEFEAT Composite Material*.

2. Optimization of Fire Resistant and Thermal Insulation Geopolymers

Table 1 below summarizes the conditions followed for the production of the optimum Fire Resistant geopolymers, which were selected in DEFEAT project to be produced by both the production processes, casting and 3D printing. It concerns for two compact alkali-activated materials, which are based on brick and ceramic tile wastes. The optimization of the fire resistant geopolymers was based on rheological (viscosity and setting time), mechanical (compressive strength) and thermal (durability and mechanical strength at high temperatures) properties. More details for the properties of these materials are given in Deliverable 6.1 of DEFEAT Project.

Table 1. Synthesis conditions of the optimum Fire Resistant Geopolymers

Parameter	BFR(1)	CTFR(1)
S/L ratio, g/mL	2.5	3.4
Alkaline solution / Concentration	KOH / 8M	KOH / 8M
Alkali activator	KOH and $Na_2SiO_3\ _x\ H_2O$ solutions	KOH and $Na_2SiO_3\ _x\ H_2O$ solutions
$Na_2SiO_3xH_2O$ / KOH, v/v in activator	1.6 : 1	1.6 : 1
Curing temperature, ^oC	50	50
Curing time, days	7	7

(1)Abbreviations: BFR: Brick-based fire resistant geopolymer; CTFR: Tile-based fire resistant geopolymer

In Table 2 that follows, the synthesis conditions of the optimum Thermal Insulation geopolymers selected in DEFEAT project to be produced by the casting production process are given. It concerns for four porous alkali-activated materials, two of which are based on brick waste and two on ceramic tile waste. The optimization of the heat insulation geopolymers was based on rheological (viscosity and setting time), physical (density), mechanical (compressive strength) and thermal (thermal conductivity) properties. More details for these materials are given in Deliverable 6.1 of DEFEAT project.

Table 2. Synthesis conditions of the optimum Thermal Insulating Geopolymers

Parameter	B_CDW019(2)	WB-2.1-K8-1(2)	T_CDW_09(3)	WT3.0-K8-1(3)
S/L ratio, g/mL	3.0	2.1	3.3	3.0
Alkaline solution / Concentration, Molarity	KOH / 8 M	KOH / 8 M	KOH / 8 M	KOH / 8 M
Alkali activator			KOH (8M) & $Na_2SiO_3xH_2O$	
$Na_2SiO_3xH_2O$ / KOH ratio (v/v in activator)	-	-	1 : 1	-
Al powder, % wt	-	-	0.1	-
H_2O_2, % vol	3.5	9.4	-	13.4
Curing time	7 days	24 h	7 days	24 h
Curing temperature, ^oC	70	70	70	70

(2) Brick-based Thermal Insulating (porous) geopolymer, BTI
(3) Ceramic Tile-based Thermal Insulating (porous) geopolymer, CTTI

3. Flowsheets of the Fire Resistant and Thermal Insulation Geopolymers Production by Casting Process

Figure 1 illustrates the production flowsheet of the Fire Resistant geopolymers BFR and CTFR, following the casting process. Similarly, Figure 2 shows the flowsheet of the casting production process of the Brick-based Thermal Insulation geopolymer BTI and Ceramic Tile-based Thermal Insulation geopolymer CTTI.

Details on operating parameters at the different production stages of both types of geopolymers are also given in these flowsheets. Furthermore, data estimating the energy consumption at the most energy-intensive process steps (milling / mixing / curing) are included.

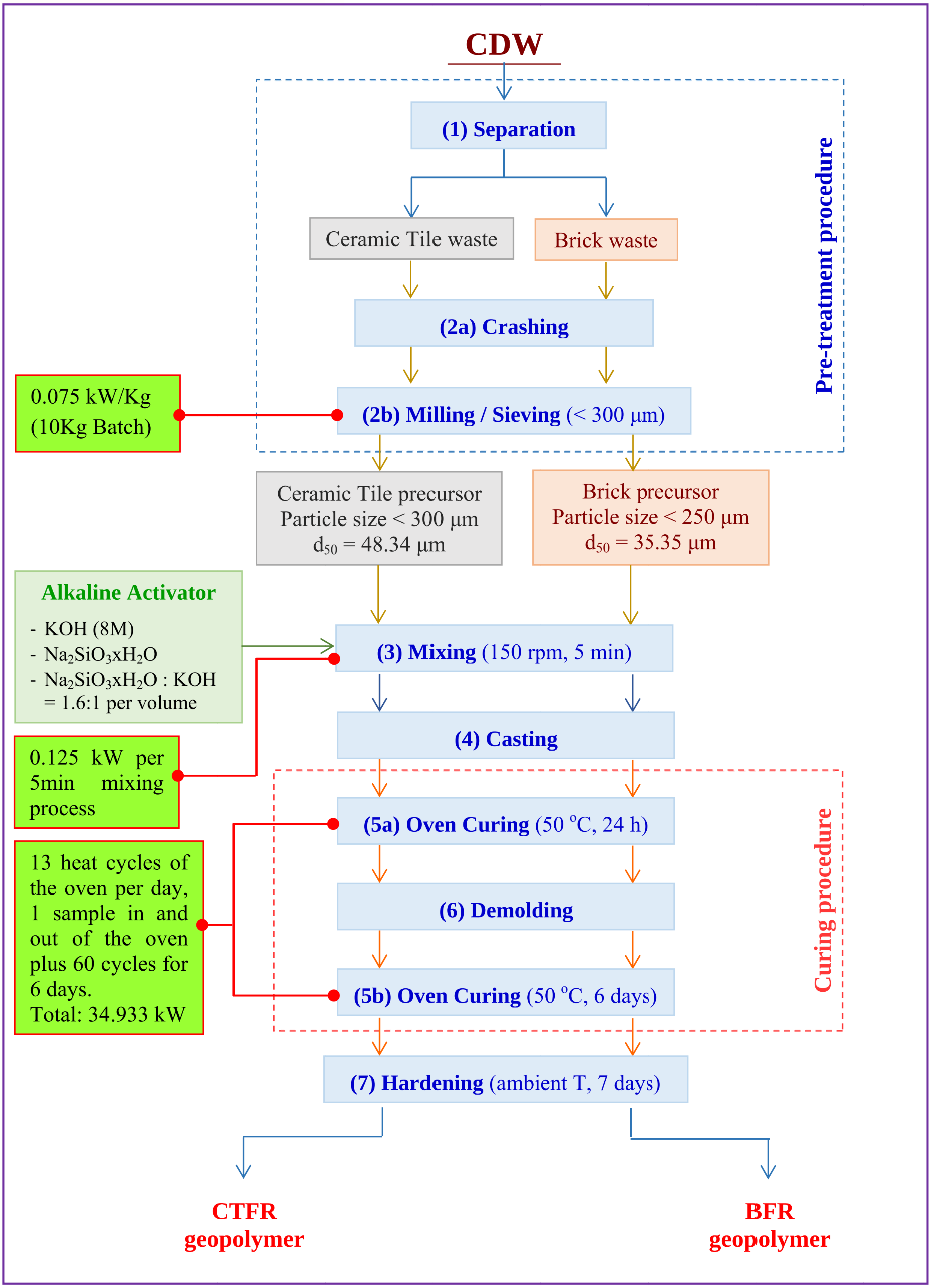

Figure 1. Flowsheet of the Fire Resistance (compact) geopolymers production by casting process.

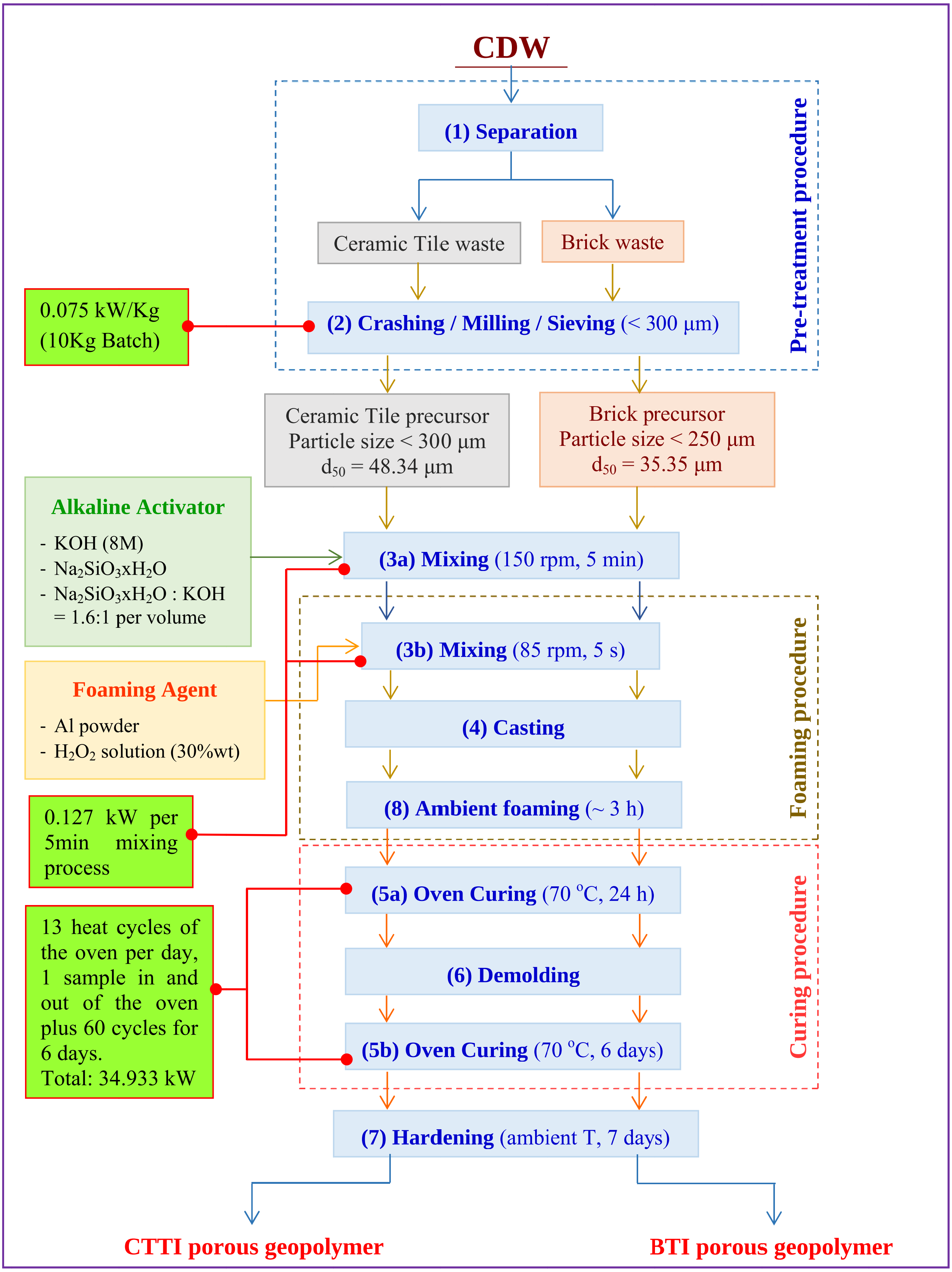

Figure 2. Flowsheet of the Thermal Insulation (porous) geopolymers production by casting process.

4. Flowsheet of Casting Production Process of the DEFEAT Composite Material

Figure 3 presents the production flowsheet of the DEFEAT Composite Material, according to the casting process. In casting process and following the bonding method for connecting together the Fire Resistant and the Thermal Insulating materials, the required geopolymeric pastes are first prepared and then, they are casted as follows: the foamed geopolymeric paste is casted on the surface of that of the fire resistant geopolymer. In this case, the preparation of the geopolymeric paste for the Fire Resistant material is done according to steps (1) – (4) of the corresponding process given in Figure 1. Similarly, the paste for the Thermal Insulating geopolymer is prepared according to steps (1) – (8) of the relevant process described in Figure 2.

In the case that the fixing method is adopted to combine the Fire Resistant and the Thermal Insulating geopolymers into the DEFEAT Compact Material, the two geopolymers are separately produced by casting and then, are joined with fireproofing anchors. The flowsheet of this production process is not included in this Deliverable, as it is simple and totally based on the casting production processes of the two combined geopolymers.

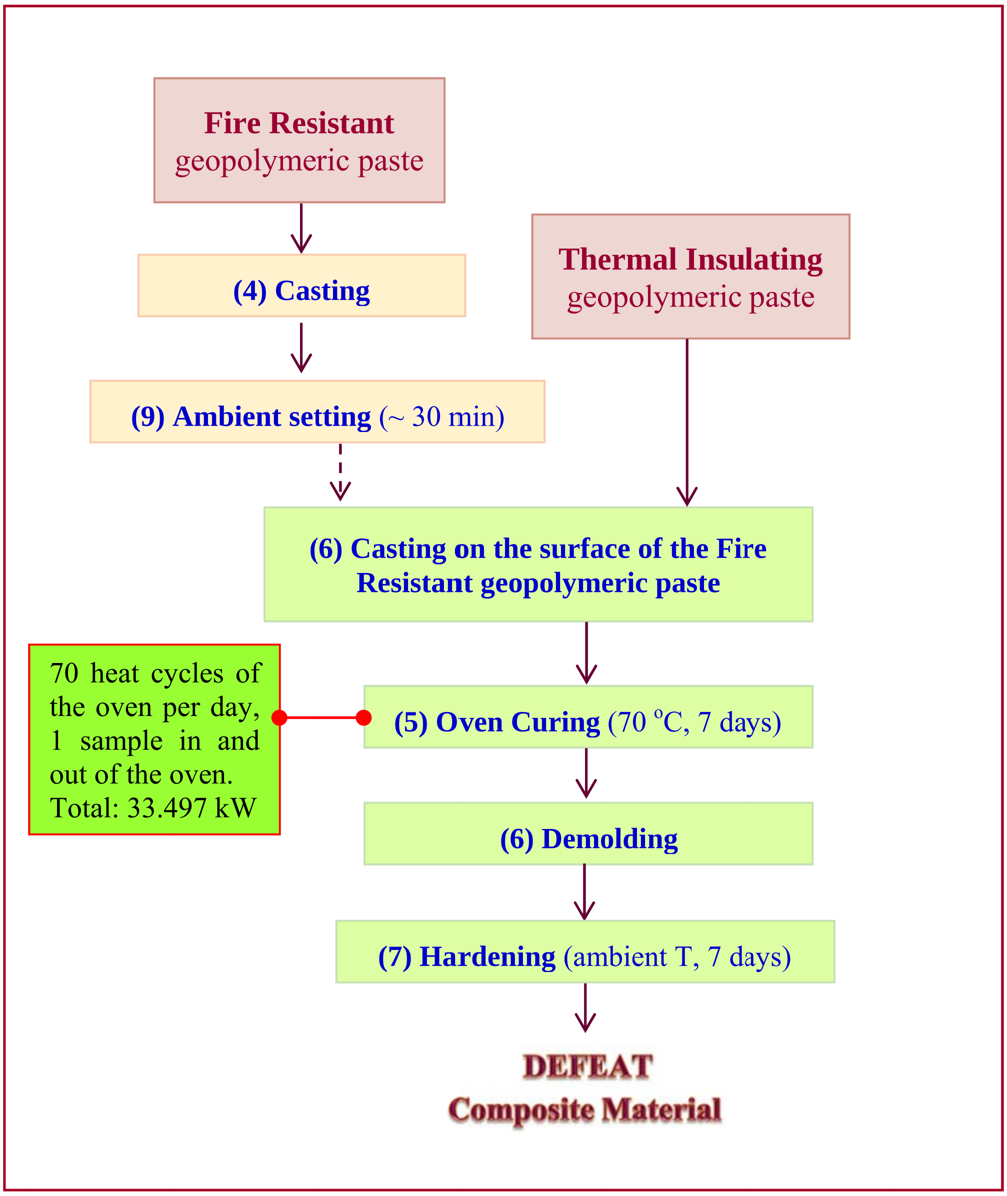

Figure 3. Flowsheet of the casting production process of DEFEAT Composite Material.

5. Flowsheet of 3D Printing Production Process of the DEFEAT Composite Material

Figure 4 illustrates the production flowsheet of the DEFEAT Composite Material by the 3D printing process. Practically, the 3D printed Composite Material consists of two parts: a compact one that serves to protect the material against fire and a second part with voids that is used as thermal insulator. The geopolymeric paste that is used for printing the required patterns of the DEFEAT Composite Material is prepared according to the synthesis conditions of the optimized Fire Resistant (compact) geopolymers (Table 1 of this Deliverable). More precisely, this paste is prepared according to steps (1) – (3) of the process described in Figure 1 of this Deliverable.

Regarding the 3D printing production process, the compact part of the Composite Material is first printed (step 1 in Fig. 4) and then, the pattern with the voids is printed (Step 2 in Fig. 4).

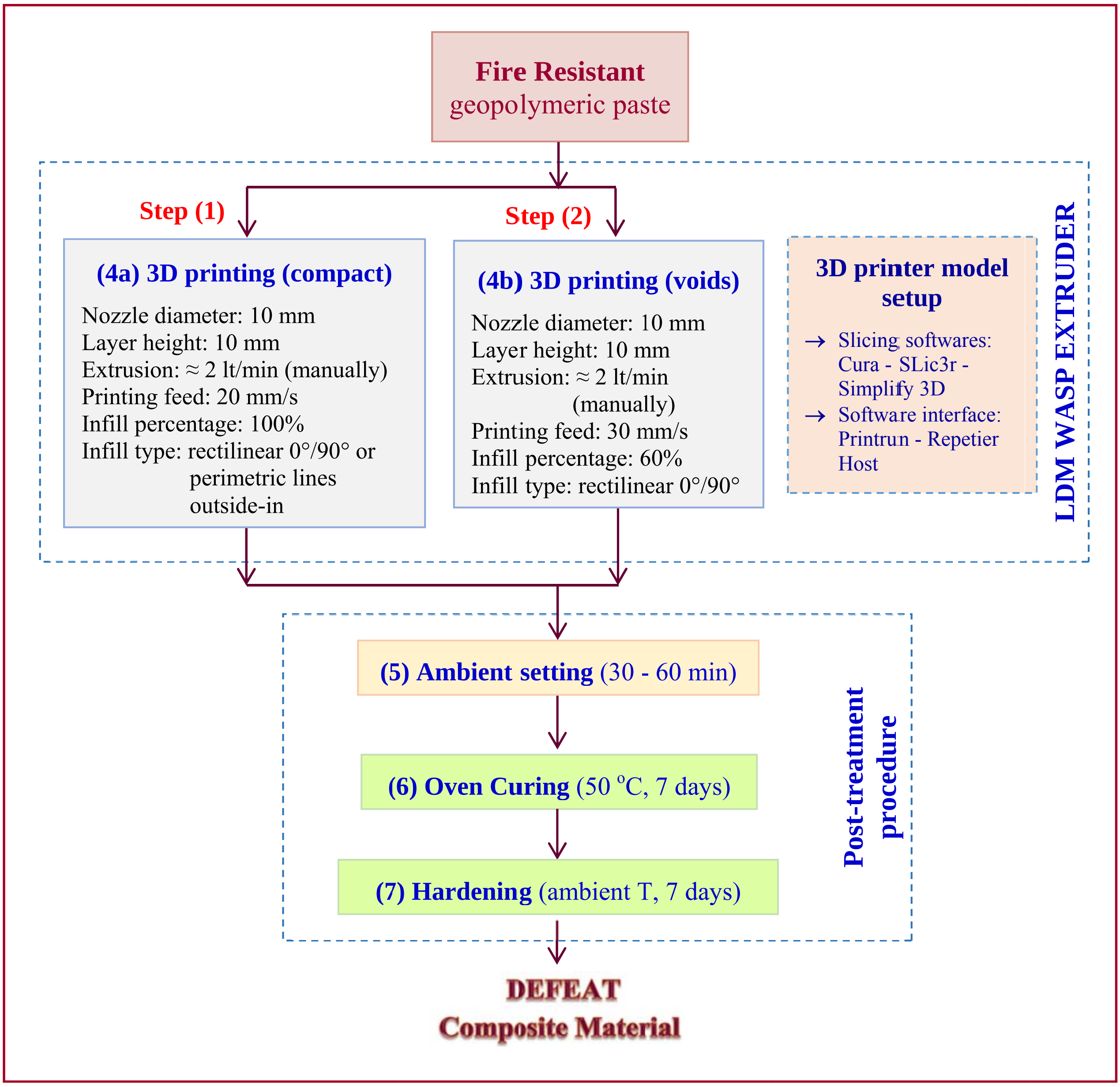

Figure 4. Flowsheet of the DEFEAT Composite Material production by the 3D printing process.

6. Conclusions

The present Deliverable 6.2 includes the flowsheets for the production of the new *DEFEAT Composite Material*, according to the casting and the 3D printing processes.

Particularly, the casting process can be used for the production of the *DEFEAT Composite Material* on-site, as well as off-site. Following this production route, the Fire Resistant and the Thermal Insulation geopolymers are separately produced and then, they are combined into the *Composite Material* either, by fixing the two geopolymers with fireproofing anchors or by applying a freshly prepared layer of the one geopolymer onto the surface of the other one that could be fresh or hardened.

The 3D printing process takes advantage of the voids that the appropriate patterning can form in the volume of a material, in order to achieve a lightweight geopolymer with simultaneous low thermal conductivity and sufficient mechanical strength. Using an appropriate mix design for fire resistant geopolymers, the final material can serve as fire-resistant and thermal insulator at the same time, thus yielding the Composite Material focused on the DEFEAT project.

As a final conclusion, both manufacturing processes separately or as a combination can be used for the production of the DEFEAT Composite Material, from the technical point of view. In the frame of DEFEAT Project, both processes will be used to demonstrate the upscaling of the *DEFAT Composite Material* with the production of near-industrial-sized boards in Task 7.2, thereof widening the possibilities for future industrial applications of the new geopolymer facade with the unique properties.

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