Blast and Fire Resistant Material

B A M

EXCELLENCE/0421/0137

DELIVERABLE D4.1

FLOWSHEETS OF MATERIALS PRODUCTION

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EXECUTIVE SUMMARY

Deliverable "***D4.1-Flowsheets of Materials Production***" presents the production flowsheets for the innovative materials developed in the research project "Blast and Fire Resistant Material (BAM)". These materials include the Hybrid Laminated Material (HLM) (designed and developed in *WP3, Task 3.1)* and the Smart Composite Geopolymer Concrete (SCGC) (designed and developed in *WP3, Task 3.2)*. The UHPFRC layer of the HLM production process was studied using the casting method, while the fire resistant geopolymer (FRG) layer of the HLM and the SCGC were studied using both casting and 3D-printing processes. Deliverable ***D4.1*** also includes the synthesis and curing conditions for the optimized UHPFRC and FRG materials composing the HLM, as well as the optimized SCGC material.

In *WP3, Task 3.1*, the consortium successfully developed an UHPFRC material with compressive strength exceeding 150 MPa and a flexural strength exceeding 22 MPa, indicating suitability to be used for blast- and impact-resistant applications. A low-cost and sustainable geopolymer with adequate compressive strength (~25 MPa) to be used for the passive fire protection of buildings and constructions was also developed using fly ash, an industrial by-product. The integration of these two materials into the HLM was also completed.

In *WP3, Task 3.2*, the consortium designed and developed a geopolymer material based on a metallurgical slag (ground granulated blast furnace slag) to serve as blast-, impact- and fire-resistant material (SCGC) for buildings and constructions. The SCGC material was optimized for compressive and flexural strength, focusing on crucial parameters of the geopolymerization process for both casting and 3D printing production methods (*WP3, Task 3.3*). More precisely, the viscosity and setting time of the geopolymeric paste were evaluated to determine the optimal SCGC materials for both production methods. Further investigations assessed the mechanical strength (compressive and flexural), apparent density, and structural stability of SCGC materials at high temperatures. The fire resistance and durability of the optimized materials were evaluated in *WP4, Task 4.1* and the results are included in the project Deliverable "***D4.1-Validation of Materials in the Laboratory***".

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1. Optimization of Blast- Impact- and Fire-Resistant Materials

Table 1 summarizes the mixtures' design details for the optimized UHPFRC mixture used as the blast- and impact-resistant layer in the HLM. Mechanical properties determined for the optimum mix design are given in Deliverable D3.1.

Table 1: Optimized UHPFRC Mixture Constituents

Constituent	**Content (kg/m^3)**
Cement	880
Microsilica	220
Reference Sand	833
Water	172
Superplasticizer	67
Steel fibers 6mm	80
Steel fibers 13mm	80
PVA fibers	13
Water/Binder ratio	*w/b = 0.16*

Table 2 includes the synthesis and curing conditions, along with important geopolymerization ratios of the optimal FRG material that will be used as the fire-resistant layer in HLM (Deliverable D3.1).

Table 2: Synthesis and curing conditions of the optimal FRG material.

Synthesis Conditions	
Parameter	***Value***
Mass of FA (g)	360
Mass of GGBFS (g)	40
Mass of SF (g)	0
Volume of 7 M NaOH (mL)	72.4
Molarity of NaOH solution (M)	7
Volume of Na-silicate solution (mL)	32.6
Ratio	***Value***
[NaOH] in alkaline activator (M)	5.9
S/L ratio (g/mL)	3.8
SS to SH volumetric ratio (v/v)	0.45
SiO_2/Na_2O molar ratio (Ms)	0.637
Curing Conditions	
Parameter	***Value***
Temperature (ºC)	30
Time (days)	7

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Also, Table 3 includes the synthesis and curing conditions, and important geopolymerization ratios of the optimal SCGC material (Deliverable D3.2).

Table 3: Synthesis and curing conditions of the optimal SCGC material

Synthesis Conditions	
Parameter	***Value***
Mass of GGBFS (g)	800
Mass of Silica sand	0
Mass of Silica fume (g)	0
Volume of 7 M NaOH (mL)	100
Molarity of NaOH solution (M)	7
Volume of Na-silicate solution (mL)	150
Fibers (% wt.)	0
Ratio	***Value***
S/L ratio (g/mL)	3.2
SS to SH volumetric ratio (v/v)	1.5
Curing conditions	
Parameter	***Value***
Temperature (°C)	30
Time (days)	7

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2. Flowsheet of the HLM Production by Casting Process

2.1 Production Flowsheet of the Blast- and Impact-Resistant UHPFRC Material

Figures 1 and 2 illustrate the production flowsheets of the blast- and impact-resistant UHPFRC material, with the casting process. Moreover, important details on operating parameters at the different production stages of the UHPFRC material are also given in these flowsheets. Specifically, Figure 1 presents the standard procedure for developing UHPFRC, while Figure 2 includes an additional step of ambient curing of specimens for 24 hours before demoulding.

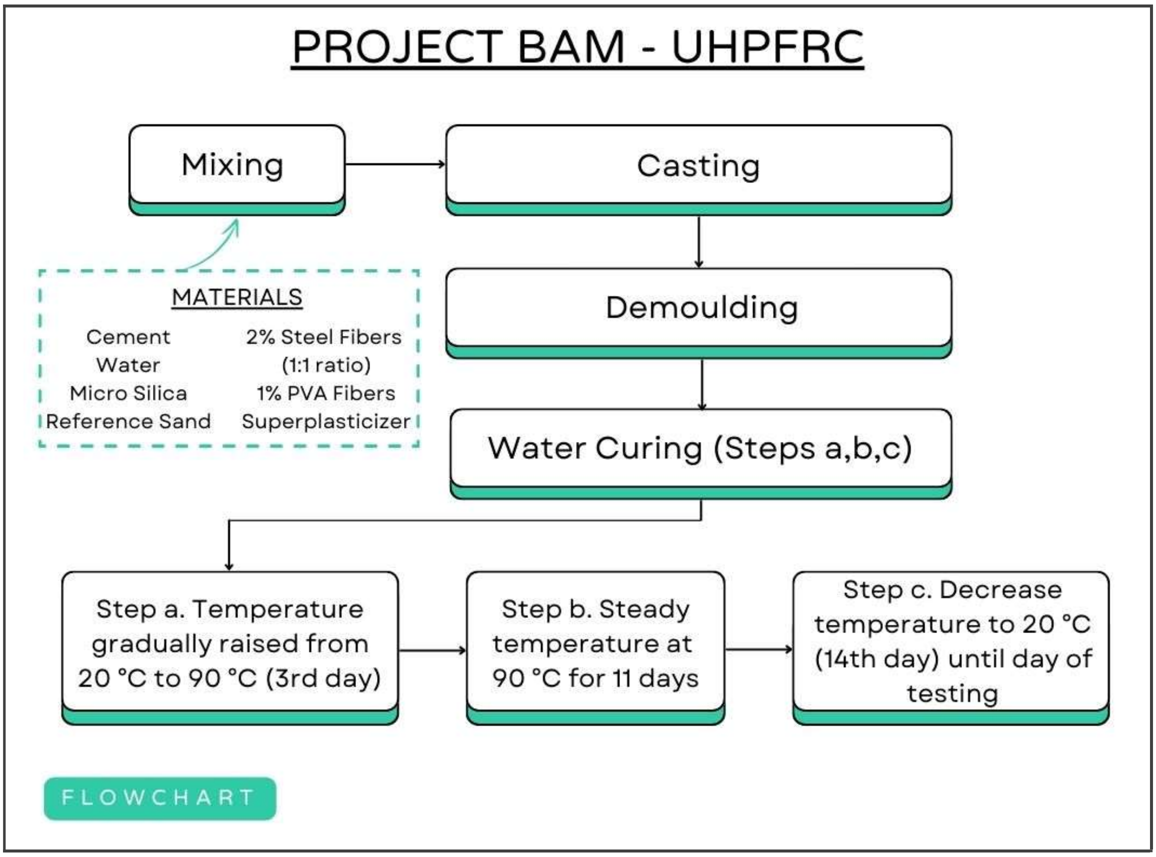

Figure 1. Production flowsheet of the UHPFRC layer providing the Hybrid Laminate Material with blast- and impact-resistance (casting process).

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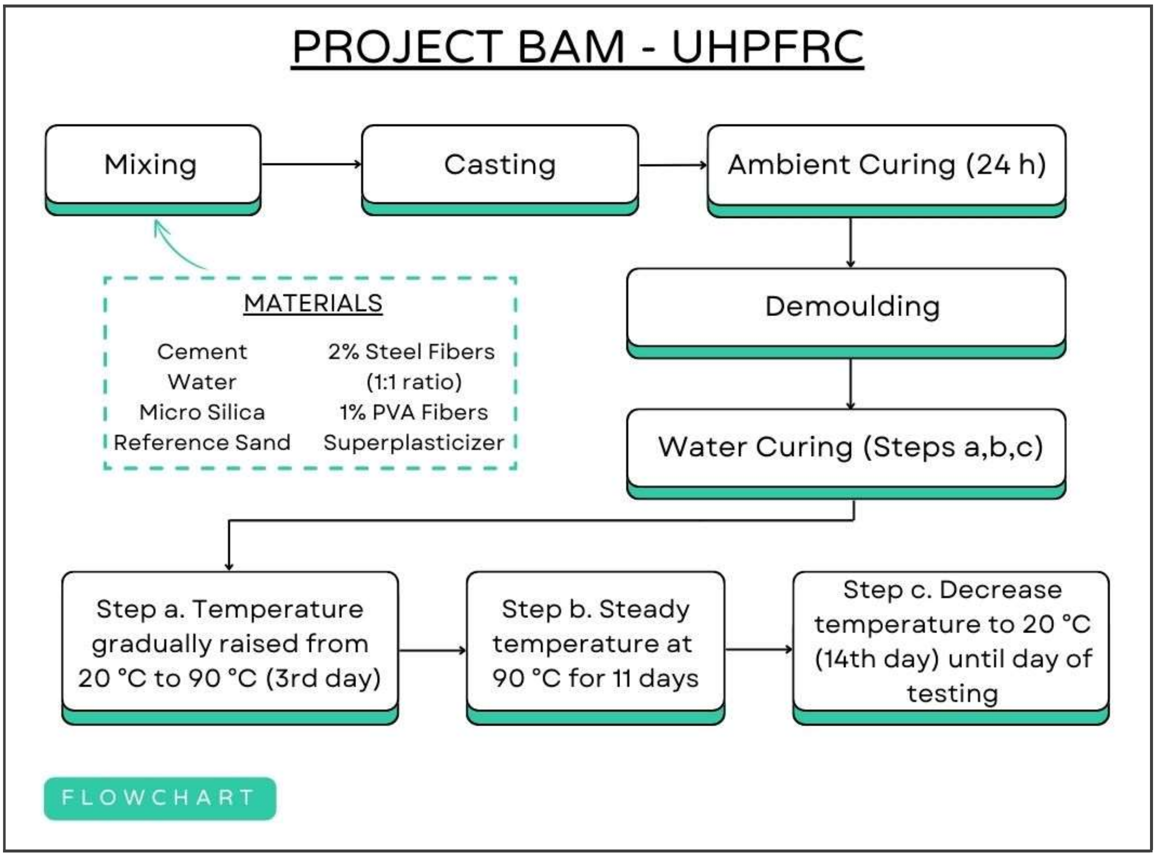

Figure 2. Production flowsheet of the UHPFRC layer providing the Hybrid Laminate Material with blast- and impact-resistance (casting process), with additional step of ambient curing of specimens for 24 hours.

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2.2 Production Flowsheet of the Fire-Resistant Geopolymeric (FRG) Material

In Figure 3, the production flowsheet (casting process) of the fly-ash based geopolymer used as the fire-resistant layer in the HLM is presented. The flowsheet includes also the operating parameters followed in the production stages of the FRG material.

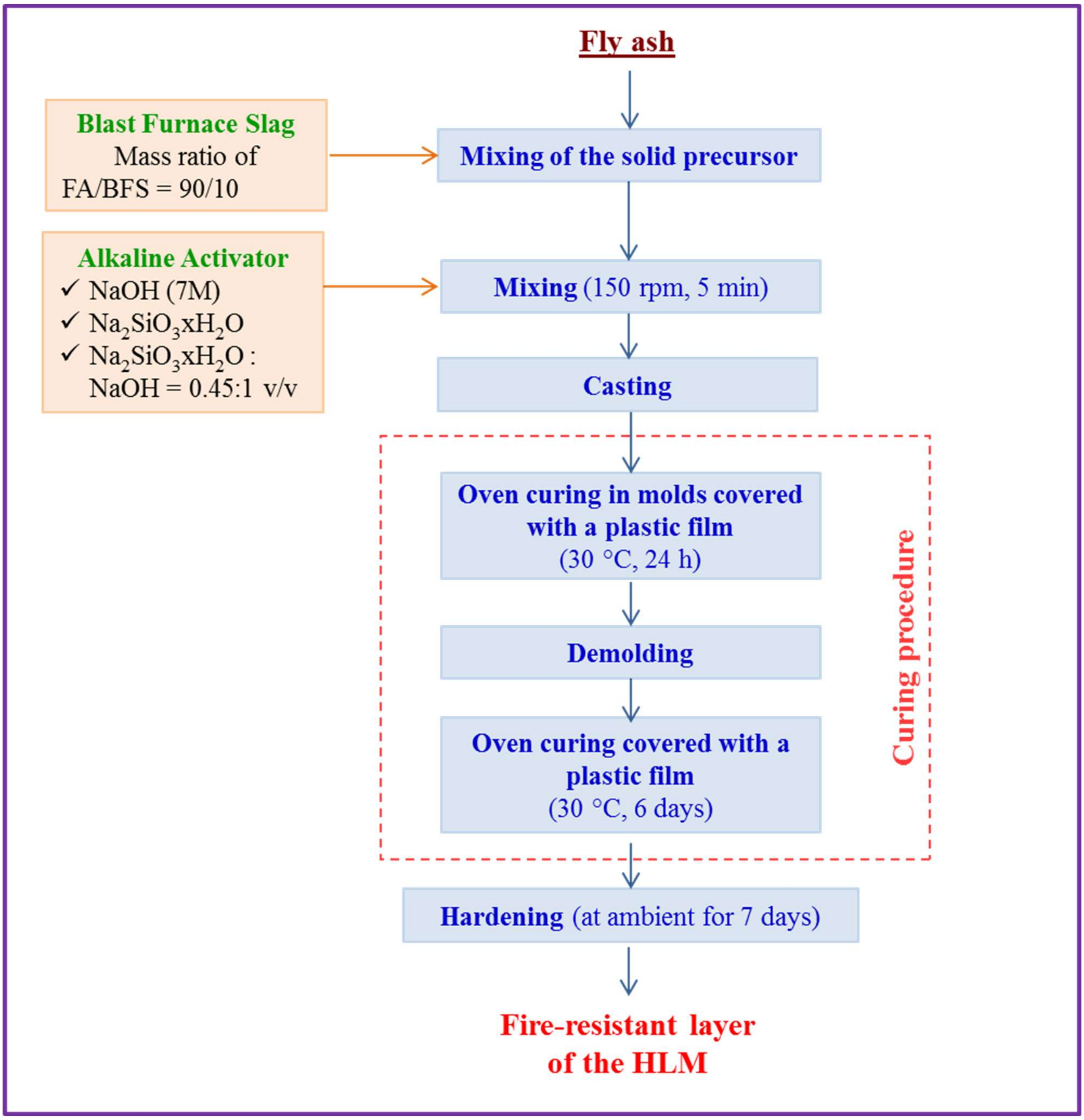

Figure 3. Production flowsheet (casting process) of the fire-resistance geopolymer (FRG) used in the Hybrid Laminate Material.

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3. Flowsheet of the SCGC Material Production by Casting Process

Figure 4 presents the flowsheet of the SCGC material production, using the traditional casting process.

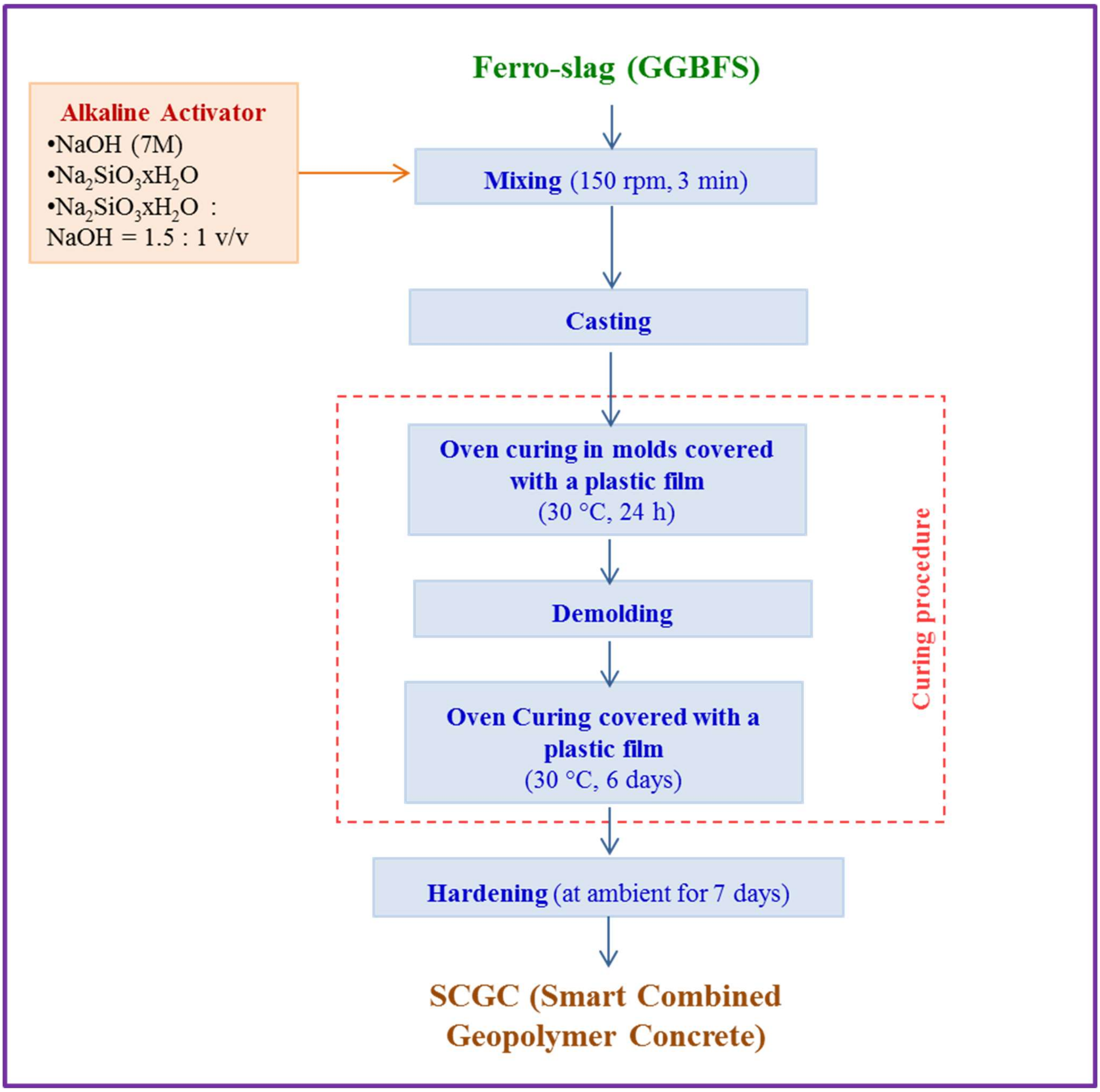

Figure 4. Production flowsheet (casting process) of the Smart Composite Geopolymer Concrete.

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4. Flowsheet of the SCGC and FRG Material Production by 3D Printing Process

Figure 5 illustrates the production flowsheet of the BAM SCGC and FRG of the HLM, by the 3D printing process. The geopolymeric pastes that are used for printing the particular materials are prepared according to the syntheses conditions explained in detail in Deliverables D3.1 and D3.2, respectively.

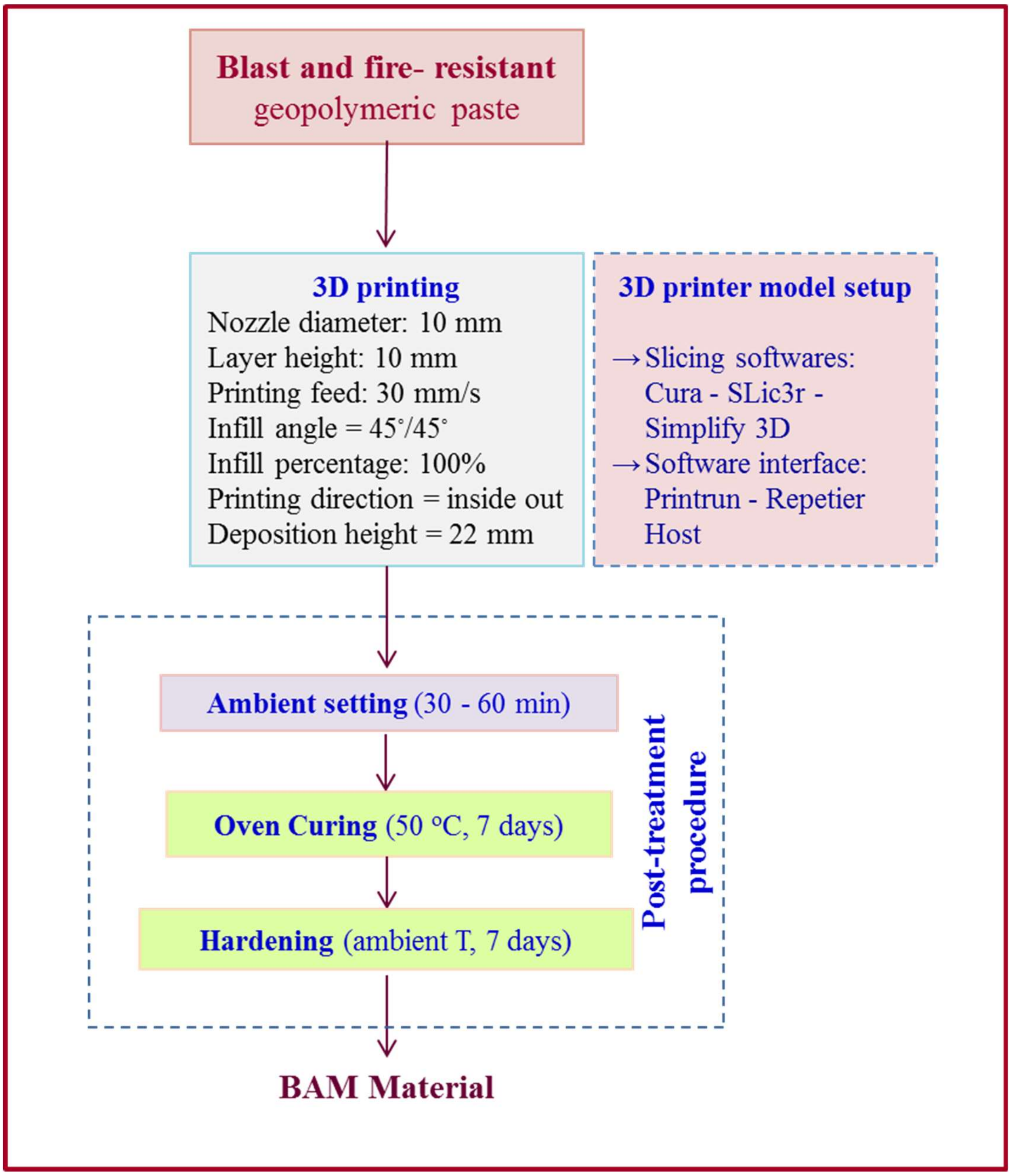

Figure 5. Flowsheet of the BAM Materials SCGC and FRG layer of HLM production, by the 3D printing process.

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5. Conclusions

Deliverable D4.1 outlines the production flowsheets for the casting and 3D printing processes used to develop the new materials in the frame of the BAM project, namely: Hybrid Laminated Material (HLM) and Smart Composite Geopolymer Concrete (SCGC).

For HLM, blast- and impact-resistant UHPFRC and fire-resistant geopolymer FRG are produced separately and then combined using one of three methods: (i) fireproof anchors, (ii) applying a freshly prepared geopolymer paste onto the surface of the other material (whether fresh or hardened), or more effectively (iii) using a suitable fire-resistant adhesive epoxy resin.

In the 3D printing process, selecting the appropriate pattern, controlling key process parameters, and continuously monitoring the viscosity of the printed pastes are crucial for successful implementation.

In conclusion, both casting and 3D printing can be used separately or in combination to produce SCGC (without fibres) and the fire-resistant layer of HLM from a technical standpoint. However, 3D printing of fibre reinforced SCGC and UHPFRC was not practically feasible due to the large volume of steel fibers, despite significant efforts by the research team.

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