FORMULATION DEVELOPMENT OF THERMAL-INSULATING DRY-MIX PLASTERS BASED ON POROUS AGGREGATES AND MODIFYING ADDITIVES

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Abstract. This thesis reviews the scientific literature on thermal-insulating dry plaster mixtures incorporating porous aggregates (perlite, vermiculite, expanded polystyrene granules, aerogel, and cenospheres) together with polymeric and mineral modifiers. The principal approaches to formulation optimization are identified.

Reducing heat losses from buildings is one of the key objectives of energy conservation in the construction sector. A substantial proportion of building energy consumption is attributable to heating and cooling; consequently, thermal insulation requirements for building envelopes are becoming increasingly stringent [1]. When produced as dry construction mixtures, thermal-insulating plasters perform two functions simultaneously: they level the surface and improve the thermal resistance of walls. Dry mixtures also offer advantages in terms of consistent quality, ease of transportation and storage, and reduced dosing errors at construction sites.

Conventional cement–sand plaster has a relatively high thermal conductivity (approximately 0.8–1.0 W/(m·K)). The principal means of reducing it are to lower the material density and introduce both closed and open pores into its structure. However, increasing porosity may adversely affect mechanical strength, adhesion, and water resistance. The combined selection of porous aggregates and modifying additives therefore remains an important scientific and technical challenge.

Overview of thermal insulation materials. Jelle [1] comparatively reviewed conventional materials (mineral wool, expanded polystyrene, and polyurethane) and advanced solutions (vacuum insulation panels, aerogels, and gas-filled panels). By evaluating their thermal conductivity, fire resistance, long-term durability, and environmental characteristics, the author outlined the requirements for an ideal insulation material. This study provides a theoretical basis for selecting aggregate types when designing plaster formulations.

Aerogel-based plasters. Stahl et al. [2] developed a thermal-insulating plaster containing aerogel granules for both exterior and interior wall applications and investigated its hygrothermal properties. Their findings indicated that the aerogel aggregate considerably reduced thermal conductivity relative to conventional plasters while maintaining water vapor permeability. Ibrahim et al. [3] experimentally and numerically investigated a wall system coated with aerogel-based plaster, addressing heat losses and the optimization of layer thickness. They also highlighted the high cost of aerogel as a limiting factor for widespread application.

Analysis. The principal conclusions drawn from the reviewed studies can be summarized as follows:

1. The lowest thermal conductivity can be achieved using nanoporous aggregates such as aerogel. However, because of their high cost, combining them with more affordable mineral aggregates (perlite, vermiculite, and cenospheres) is advisable.

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2. Lightweight aggregates increase the water demand of the mixture, which may reduce mechanical strength and adhesion. These effects should be compensated for by incorporating polymeric and water-retaining additives.

3. Workability, drying shrinkage, and moisture-related behavior require separate optimization.

A comparison of the main porous aggregates suitable for thermal-insulating plasters is presented in Table 1.

Table 1. Comparative characteristics of porous aggregates for thermal-insulating plasters

Porous aggregate	Bulk density, kg/m³	λ, W/(m·K)	Advantages	Limitations
Expanded perlite	50–200	0.04–0.07	Low cost; mineral and non-combustible; locally available raw material	High water demand; brittle; may break down during processing
Vermiculite	80–200	0.06–0.10	Fire-resistant; lightweight; thermally stable	High water absorption; low strength due to its layered structure
Expanded polystyrene granules	10–30	0.033–0.040	Very low density and thermal conductivity; low water absorption	Combustible; weak adhesion to the cement matrix
Aerogel granules	70–150	0.012–0.020	Very low thermal conductivity; maintains water vapor permeability	High cost; low mechanical strength
Cenospheres (fly ash hollow spheres)	300–450	0.08–0.12	Closed pores; good strength; low water demand	Relatively limited thermal insulation performance; limited supply

Note: The values are approximate and are based on typical literature data; actual properties depend on particle size fraction and manufacturer.

Research Direction and Formulation Development Methodology

The proposed base formulation of the dry mixture is planned to comprise the following components:

- Binder: Portland cement or a combination of cement with building gypsum/lime;
- Porous aggregate: expanded perlite and vermiculite (taking into account the availability of local raw materials), with cenospheres or a small proportion of aerogel granules added if necessary;

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• Modifying additives: redispersible polymer powder (to improve adhesion and flexibility), cellulose ethers (for water retention), air-entraining and hydrophobic additives, and, if required, microfibers (to enhance crack resistance).

The formulation will be selected using design-of-experiments methods. The following properties will be determined: dry density, thermal conductivity, compressive and flexural strength, adhesion strength to the substrate, water absorption, water vapor permeability, and freeze–thaw resistance. The objective is to achieve an optimal balance of performance characteristics by minimizing thermal conductivity while maintaining the required mechanical strength and adhesion.

Expected Results and Conclusion

The literature review demonstrates the need for coordinated selection of aggregate type, porosity, and polymer additive content when developing thermal-insulating plaster formulations. Although advanced aggregates such as aerogels offer high thermal insulation efficiency, compositions based on locally available mineral porous aggregates and targeted modifiers appear more economically promising for large-scale applications. The anticipated practical outcome of this work is the development of an energy-efficient, easy-to-apply dry construction mixture based on locally sourced raw materials.

References

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