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Thermal performance of sawdust and lime-mud concrete masonry units

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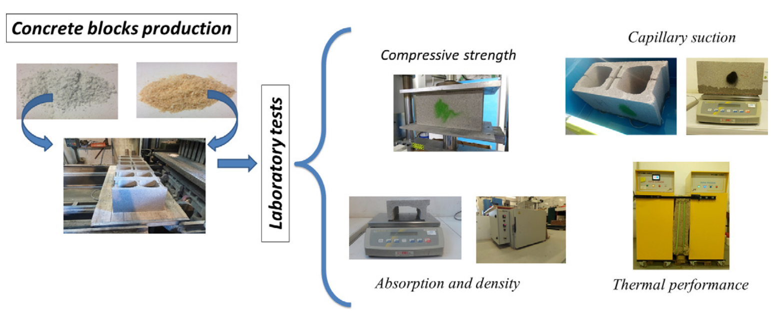
HIGHLIGHTS

- Enhanced concrete blocks using forestry and paper pulp industry by-products.
- Sawdust concrete masonry walls have better thermal resistance than ordinary walls.
- The use of sawdust as a fine-aggregate replacement reduces compressive strengths.
- Lime mud incorporated as a cement substitute counteracts reductions in strength.

GRAPHICAL ABSTRACT



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ABSTRACT

Over the past three decades, growing interest in the properties of thermal envelopes and their enhancement has led to the development of new sustainable materials. Nevertheless, Concrete Masonry Units (CMUs) with negligible thermal properties are still widely manufactured in unsustainable processes for use in the thermal envelopes of buildings. Hence, this research aims to reuse certain by-products for the development of CMUs with better thermal properties. In addition to the reference concrete, one set of blocks was manufactured with 5% sawdust in substitution of fine aggregate and another set of blocks with the same level of fine aggregate replacement together with 15% lime mud in substitution of cement. The physical, mechanical, and thermal performance of the CMUs evaluated in this paper showed that the addition of sawdust in the CMUs improved their thermal properties. On the other hand, the addition of lime mud partially counteracted the decrease in strength caused by the incorporation of the sawdust.

1. Introduction

Currently, there is a growing interest in developing new sustainable construction materials with better thermal properties for the thermal envelopes of buildings. However, Concrete Masonry Units (CMUs) with negligible thermal properties continue to be widely used in the thermal envelopes of buildings and are still manufactured following unsustainable approaches. Hence, this research seeks to reuse some waste materials as by-products from the timber and paper mill industries for the development of eco-friendly CMUs with better thermal properties for the construction sector.

Waste materials obtained from manufacturing processes have become one of the main environmental concerns worldwide. It is noteworthy that during 2014, if we consider all economic and household activities, total waste production of the EU-28 member states amounted to 2500 million tons [1]. Besides, the poor energy efficiency of most buildings is a further cause of energy poverty. For instance, the residential sector represents 27% of the world's

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energy consumption and 17% of CO_2 emissions [2]. In this regard, the European Commission (EC) has issued certain Directives [3,4]: on the one hand, establishing strict requirements for waste reduction, management, and recycling that promote moves towards a circular economy. On the other hand, the EC seeks to accelerate the cost-effective renovation of existing buildings. Therefore, the reuse of those waste materials as by-products is tenable for the development of building envelope materials with better thermal properties.

Concrete Masonry Units (CMUs) are widely used, especially in developing countries, as components of the building envelope. They present many advantages such as, economy, durability, great flexibility of plan form, and spatial composition. Furthermore, the construction of masonry walls can fulfill diverse roles including structure, sound insulation, and fire protection [5]. There is a growing interest in finding ways that will partially substitute some of their components such as cement or aggregates for other by-products [6]. Several studies [7–16] have been conducted on this subject, producing environmentally friendly CMUs while maintaining an acceptable level of compressive strength. All the above research agrees that the incorporation of by-products in the mix reduces manufacturing costs and minimizes the environmental impact of the extraction of the raw materials.

Recent efforts [17–22] have been conducted along similar lines, but they have been focused on one of CMUs weaknesses, i.e. thermal properties. The minimum values specified in the standards required for high efficiency buildings are not usually met by single-width CMU walls. They usually need to be integrated into thermal insulation layers. The aim of these research is to improve the thermal properties of CMUs through the use of by-products, e.g. crumb rubber, bottom ash, hemp fibers, hurds, fly ash, sewage sludge ash and textile effluent sludge, as part of their components. However, the challenge of this investigation has been to comply with the mechanical strength requirements as, in general, the optimization of thermal properties is dependent on the presence of voids in the concrete, while high density is required for high mechanical strength rather than voids [23,24].

Annually, large amounts of sawdust and lime mud are obtained as by-products from the forestry and paper pulp industries and are widely available in several countries. While the former results from sawing timber for the manufacture of furniture and wooden products, the latter is obtained during the conversion of wood into pure cellulose fibers through the kraft process. It is a solid waste generated in a causticization reaction in the alkali recycling process of the paper manufacturing industry.

Depending largely on the average width of the saw, the thickness of the sawn timber and the technology of the sawing process, between 10% and 13% of each log is reduced to fine sawdust particles [25]. Their physical and chemical properties may vary notably according to the species of tree, the geographical location, the sawing technique and, even, the particle size [26–28]. Sawdust is mainly reused for particleboard manufacture, biofuel, and animal mulching [29–31].

Previous studies [27,32,33] have assessed the effect of incorporating sawdust in CMUs. Adebakin [27] evaluated the density of blocks with a mix ratio of 1:8 (one part of binder to eight parts of sand). The production mix of the blocks was prepared by partial replacement of sand with varying proportions (10, 20, 30, and 40%) of sawdust. The results showed that the sawdust additions reduced the unit weight of the block, an effect that increased at higher proportions. Ogundipe [32] examined the use of this by-product for concrete blocks in load and non-load bearing walls. These blocks were produced from the nominal mixes 1:1:2, 1:1.5:3, and 1:2:4, with w/c ratios of 0.6. The nominal mixes 1:1:2 and 1:1.5:3 were found to have a compressive strength of 18.33 Mpa and 10 Mpa at 28 days, which satisfied the requirements of the ASTM C-39 for load and non-load bearing walls, respectively. On the contrary, mix 1:2:4 failed to satisfy the minimum requirement for non-load-bearing walls. Turgut et al. [33] manufactured brick by replacing limestone powder waste with sawdust, in proportions ranging from 10 to 30% by weight. Their results showed that the addition of sawdust increased porosity, thus decreasing its thermal conductivity. The reduction in the thermal conductivity value of the brick sample, at replacement levels of 30%, was about 38.9% lower when compared to the control sample.

Lime mud is basically composed of calcium carbonate ($CaCO_3$) and has an estimated waste production of 0.5 m^3 per ton of pulp [34]. The main paper producer worldwide, China, produced in excess of 10 million tons in 2011 [35] and production had continued to grow annually. Like sawdust, the quality of this by-product varies notably, because of the different origins of the cellulose fibers and type of paper [36,37]. In Spain and until the most recent economic crisis, lime mud was reused in the construction sector as an additive material for cement. As demand for cement has decreased, paper companies have lobbied to dispose of their waste materials in landfill sites.

There is little research on the addition of lime mud to mortars [38,39] and concrete mixes [40], while its suitability for CMUs has not been tested. Eroðlu et al. [38] partially replaced cement (5–30% in weight) by lime mud, finding that the density was reduced as the lime mud content increased, except for the sample with the lowest level of replacement (5%), which increased by around 3.5%, when compared with the control sample. Modoro et al. [39] performed compressive tests on mortars in which varying amounts (0, 10, 20, and 30%) of cement had been replaced with lime mud. The result showed that the compressive strength of the three samples at 28 days increased by 8.4% as compared with the control mortar. In a previous study by the authors [40], the thermal conductivity of concrete manufactured by partial replacement of cement with a varying proportion (5, 10, and 15%) of lime mud was not influenced in a positive or negative way by those additions. Concrete at replacement levels of 15% lime mud showed a thermal conductivity of 1.12 W/m.K, the same as the reference sample. Other authors [41,42] also evaluated its use in cement production as an addition to the clinker. They found that the mortars mixed with this type of cement developed satisfactory mechanical strength that revealed no signs of deterioration or durability weaknesses [42]. Another lines of research has focused on its use as a calcined material to manufacture a new kind of calcium-rich material for bricks, as a substitute for ordinary lime, for production in autoclaves and as a soil ameliorant agent [35,43–46].

This research aims to improve the thermal properties of CMUs through the incorporation of sawdust as a fine aggregate replacement and lime mud as a cement replacement. Although the use of sawdust in CMUs has been previously studied in combination with waste paper, limestone dust, glass powder, and rice husk ash [25,33,47–49], blending it with lime mud has received little attention. Previous studies to date have focused on these by-products and their effects on physical and mechanical properties, while the analysis of thermal properties has hardly progressed at all. In this study, our aim is to compensate the negative influence of sawdust on compressive strength by adding lime mud, while maintaining its positive influence with regard to density and thermal properties. Three types of CMUs were cast for that purpose. In addition to the initial reference concrete mix, 5% of the fine aggregate by volume was substituted for sawdust in the second mix and in the third one, in addition to the fine aggregate replacement of the second type, a binary combination was also adopted with 15% of the cement by volume substituted for lime mud. The mechanical properties were assessed though compressive strength tests at 14, 28, and 90 days. Density, water absorption, and capillary suction tests were conducted to determine the physical