

Original Research Article

Recycling and exploitation of Construction and Demolition Wastes as additives in unsaturated polyester composite building and insulation materials; Mechanical and thermal properties Investigation

ABSTRACT

Possible effects of particle-loading of composites using unsaturated polyester resin as matrix, filled (loaded) with Construction and Demolition wastes of varying granular sizing at 30%, 40% and 50% w/w concentrations in terms of flexural strength, shear strength and thermal insulation properties were studied. Experimental testing reveals that mechanical properties of these materials are associated to fabrication parameters, such as filling agent's % w/w concentration and granulometric magnitude. Variation of unsaturated polyester/ filler analogy, leads to significant effects on flexural and shear strength, which for selected filler concentrations are improved (w/w 40%) compared to all other loading scenarios examined. Improvement of mechanical performance is even greater once filling agent of smaller grain size is used. Based on synthesis of optimum mechanical behaving composites (filler 300 μm at 40% w/w) appropriate in shape and dimensions specimens were prepared and their thermal properties were investigated. Through experimental determination of thermal conductivity coefficient λ , was measured at $0.039 \text{ W m}^{-1} \text{ K}^{-1}$, lying in the range of values, referred in literature for common insulation materials ($0.0035\text{--}0.16 \text{ W m}^{-1} \text{ K}^{-1}$). The feature of combining adequate mechanical and thermal insulation properties qualifies their utilization as building and insulation materials in construction applications.

Keywords: Composite materials, C&D wastes, filler, mechanical properties, thermal properties, insulation, unsaturated polyester

1. INTRODUCTION

As global population increases, the need for available residential buildings and infrastructure networks grows larger entraining to even greater raw materials and energy consumption demands [1]. Civil infrastructure projects and building construction sectors consume over half of material and energy resources [2].

This irrational and unsustainable exploitation model to which construction industry is related, has reasonably designated it as the highest (resource) consuming sector [3].

The importance of environmental and sustainability parameters, during all phases from planning to the construction of a building or civil infrastructure project has been outlined by many researchers and researcher groups during the last decades. Implementing approaches that enable increased

resources and energy efficiency in every distinct level of materials production and construction life-cycle are under consideration during the last decades [4-11].

Moreover, issues related with recycling and recovery of construction wastes (C&D wastes), have become crucial and discussed in many research studies [12-17].

Whilst strict environmental standards and legislative framework are in force at European Union (EU) level as far as construction sector's waste management is concerned, which have set incredibly high quantitative recycling targets the average recycling percentage rates in EU member countries hardly reach 50% [18-32].

Potentials arising by exploiting construction sector's wastes, as raw aggregates, in cheap, reliable and respectively durable materials production, have not been researched yet in great extent.

Composite materials' fast evolution and development which is related to the competitive properties they demonstrate, has entitled and appointed them, as substitutes of conventional materials, in many technical and scientific fields and applications [33-38]. Inorganic additives encapsulation positively affects characteristic material properties [39, 40].

The aim of this research is to study the feasibility of developing composite materials that incorporate C&D waste as additives and investigate if these materials exhibit appropriate mechanical and thermal properties and can be used as substitutes of common building and/or insulation materials.

2. MATERIALS AND METHODS

2.1 Raw materials and resin system

Construction and Demolition waste containing various materials such as bricks, cinder blocks, gravel, tiles, soil, glass, concrete, wall coating (plaster) was collected from a specialized C&D waste processing facility. Composition of waste was determined by means of visual inspection.

The resin used as matrix for composites was unsaturated thixotropic polyester PE6/TC system of Neotex Co., which is available in the market as a complete set (resin and curing agent).

2.2 Preparation of additive substance from C&D waste

After removing contaminants which could not be processed (such as steel reinforcement parts), by means of hand-sorting and initial weighing of collected waste, consecutive stages of sampling through laboratory splitter to ensure sample's maximal homogeneity, were performed. Crushing in a jaw-crusher took place afterwards to bring C&D waste in a more manageable size and enable further processing. Initial crushing product was placed for 24 hours in the oven to remove contained moisture. After de-humidification, sequence of sieving routines, were executed. Additional splitting-

sampling steps took place and powders of two granulometric sizes, 300 µm and 500 µm, were finally prepared through grinding in a pulverizing mill.

2.3 CDW-loaded polyester composites' mechanical behavior analysis

Mixture of unsaturated thixotropic polyester PE 6/TC adding the appropriate quantity (≈3% w/w) of curing agent, Methyl-ethyl-ketone (MEKP) and loaded with C&D waste particles (filler) under concentrations of 30%, 40%, and 50% (w/w) and micro-scale grain size powders of 300 µm and 500 µm respectively, were prepared after continuous stirring the ingredients in a pot for about 5 min. Final mixture was carefully poured into a specifically shaped mold for flexural and shear strength tests according to ASTM D 790 and ASTM D 2344 respectively. The mold containing the poured mixture was placed in a laboratory oven and thermally cured at 60°C for 20 minutes. Experiments tests to study the effects of processed (pulverized) C&D waste incorporation on composites flexural and shear properties were carried out.

2.4 CDW-loaded polyester composites' thermal insulation properties

Discoid composites of appropriate dimensions were prepared according to ASTM C177, following the same procedure as described above under the same polyester and curing agent analogy and filled at 40% (w/w) with C&D waste of 300 µm which demonstrated the optimum mechanical properties (see Fig. 1 and Fig. 2, section 3.1). After being stirred final mixture containing the desired C&D waste concentration was poured in a tray and cured in the oven at 60°C for 20 min. Thermal insulating properties of composites were defined after determination of thermal conductivity coefficient, λ , using Eq. 1

$$\lambda = \frac{\Phi * S_m}{2A(\theta_{wm} - \theta_{km})} \quad (1)$$

where:

Φ : Capacity resistance of heating surface,

S_m : Composites average thickness (cm),

A : Composites average surface area (cm²),

θ_{wm} : Composites warm surfaces av. Temp. (°C),

θ_{km} : Composites cold surfaces av. Temp. (°C).

The error involved in measurements of thermal conductivity's coefficient, λ , is ±5%. Required

calculations were performed according to the literature [41].

2.5 Experimental standards

Conforming to ASTM D 2344 (Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates) and ASTM D 790 (Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials), was taken under consideration for the accurate execution of experimental measurements of shear and flexural strength respectively. Similarly, for thermal properties experimental determination, criteria and standards established by ASTM C177 (Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus) were considered.

3. RESULTS AND DISCUSSION

3.1 C&D WASTE PARTICLE-FILLED POLYESTER COMPOSITES

3.1.1 Flexural strength

Experimental results of C&D waste particle-filled polyester composites' flexural strength are presented in Fig. 1. It is obvious that particles encapsulation within the polyester matrix results to significant modification as far as flexural strength is concerned. Once initial adding of filling substance (30% w/w) takes place, flexural strength decreases by 55.4% for composites loaded with C&D waste powder of 500 μm and 54.1% for composites filled with 300 μm powder respectively, compared to that of pure unsaturated polyester materials (matrix). Increasing filling agent's percentage to 40% has an inverse result, since at this specific concentration of additive composites' flexural strength appears to be improved by 2.95% (500 μm filler) and 2.86% (300 μm filler) in comparison to materials incorporating 30% of additive substance. It is observed that brittleness of composites studied and discussed is limited down when filler is added at this specific w/w percentage. Flexural strength appears to be improved, once 300 μm C&D waste powder is used as filling agent. Further increase of filler's concentration from 40% to 50% leads to significant decrease of flexural strength about 20.6% for composites loaded with 500 μm powder and 15.1% for 300 μm loaded ones respectively, compared to composites loaded at concentration of 40% loaded. Granular size of additive substance is another important factor that strongly affects composites' mechanical behavior. In particular, composites filled with 30% (w/w), demonstrate 2.92% decrease in flexural strength once 500 μm filling powder is used compared to these in which 300 μm filler is used. Similarly, composites loaded with 40% presented decrease of 2.84% in flexural strength and composites prepared with 50% C&D waste additive, demonstrated a reduction of 9.19% respectively.

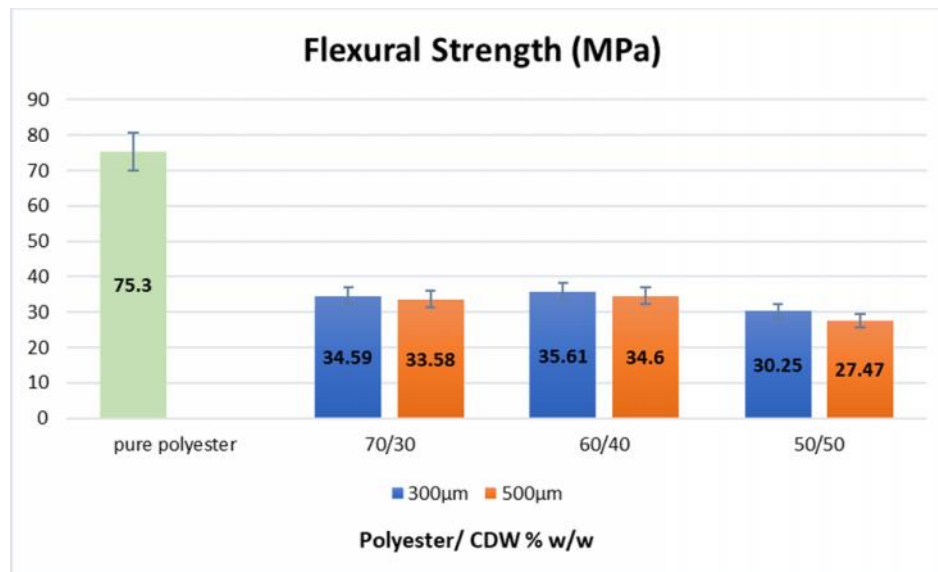


Fig. 1. CDW-filled composites' flexural strength (*Note: All Measurements include +/- 7% of error*).

3.1.2 Shear strength

As presented in Fig. 2, as analyzed above for flexural strength, it is observed that particle loading using C&D waste micro-scale powder as additive, significantly affects mechanical properties of composite materials and thus their mechanical behavior. Incorporating 30% w/w of additive in the unsaturated polyester composites, leads shear strength to decrease by 79.9% for materials incorporating additive of 500 µm and 73.3% for composites containing 300 µm additives respectively, compared to the shear strength of pure polyester composites (matrix). Increasing filling agent's concentration to 40% has an inverse result, since shear strength improves by 27.4% (500 µm filler) and 11% (300 µm filler) compared to composites filled with additives at concentration of 30%. Composites loaded with 300µm C&D waste powder, show an enhancement in shear strength compared to composites filled using 500 µm additives respectively. Further increase of loading substance from 40% to 50% leads to an even greater reduction of shear strength values about 35.4% for composites incorporating 500 µm additives and 36.4% for composites with 300 µm additive respectively compared to composites filled using C&D waste powder at concentration of 40%.

Additive's granular magnitude is of great importance as far as shear strength is concerned. Analytically, addition of filler at 30%, leads to shear strength decreasing by 24.5% if 500 µm filler is used in place of 300 µm. Correspondingly, composites containing additive at concentration of 40%

presented a shear strength downsizing of 7.42% and composites prepared adding 50% of filler demonstrated a reduction of 6.01%, once 500 μm filler was incorporated as additive instead of 300 μm one.

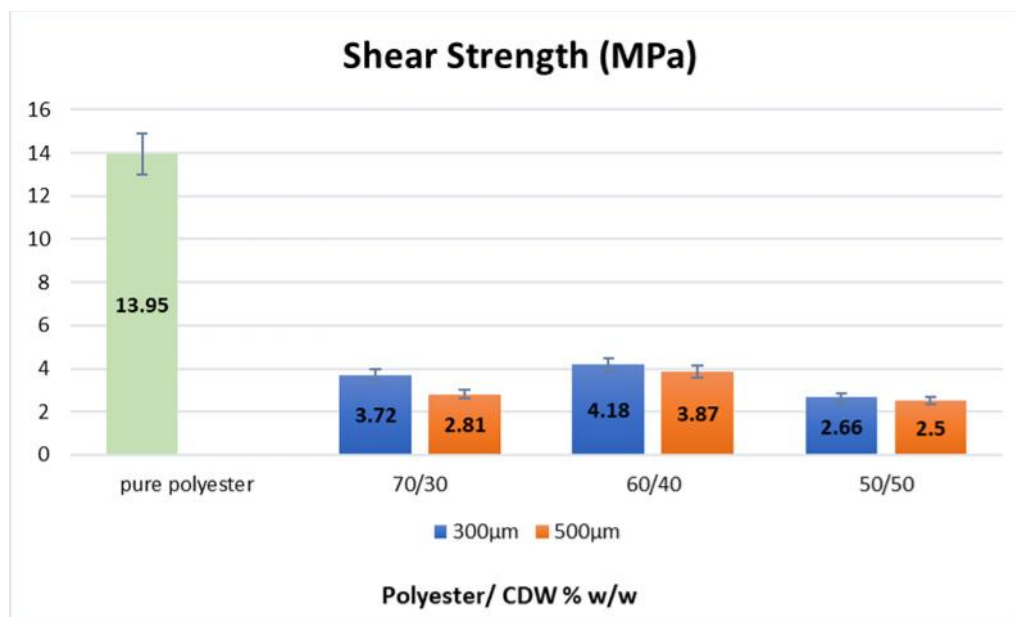


Fig. 2. CDW-filled composites' shear strength (*Note: All Measurements include +/- 7% of error*).

3.2 THERMAL INSULATION EFFICIENCY

Effects of particle loading on thermal insulation properties of composites are assessed by estimation of thermal conductivity coefficient, λ . A comparison of fabricated composites and conventional insulation materials in terms of thermal conductivity coefficients is presented in Table 1. Thermal conductivity coefficient, λ of composites under study comes up to be identical, if compared to corresponding λ values referred in literature for various insulating materials. Apart from that, examined composites exhibit enhanced thermal insulation effectiveness as compared with common building materials with satisfactory thermal insulation properties.

Table 1. Coefficients of thermal conductivity of polyester composites under study, common insulation and building materials.

Material	Polymer matrix Polyester/ MEKP (% w/w)	Additive (filler) CDW (% w/w)	Coefficient of thermal conductivity, λ ($\text{W m}^{-1}\text{K}^{-1}$)	Granular magnitude of filler (μm)
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C&D waste-loaded composite*	70	30	0.039	300
Commercial Unsat. Polyester*	100	-	0.05	
Expanded Polystyrene (XPS)	100	-	0.034-0.038**	
Extruded polystyrene (EPS)	100	-	0.033-0.035**	
Polyurethane foam (PUR)	100	-	0.023 -0.026**	
Plastics foamed	100	-	0.030**	
Insulating brick		-	0.15**	
Common Building Brick		-	0.6-1.0**	
Unsat. Commercial Polyester			0.05**	
Gypsum board			0.17**	

* Experimentally determined

** Source: https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

4. CONCLUSIONS

Polyester composites incorporating processed C&D wastes in powder form as additives, in granular magnitudes of 300 µm and 500 µm and concentrations of 30%, 40% and 50% (w/w) respectively, demonstrate satisfactory mechanical and thermal insulation properties. As validated from the experimental results comparative analysis, composite materials incorporating 300 µm filler under concentration of 40% (w/w) exhibited optimum flexural and shear strength properties compared to all other studied loading scenarios. Custom-built composites (i.e. shape, composition, dimensions) were prepared, based on synthesis characteristics of optimum mechanical behaving composites in terms of additive granular size and concentration. Experimental measurement of their thermal conductivity coefficient reveals that besides mechanical efficiency they also exhibit very good thermal insulation properties compared to corresponding data referred in literature for conventional insulation materials and can be used in construction applications as building and insulation materials.

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