ENERGY EFFICIENCY ASPECTS OF RECYCLED AGGREGATE CONCRETE

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Abstract

One of the basic sustainability targets specified in Agenda 21 for Sustainable Construction is reduction of non-renewable raw material consumption. Since concrete is widely used construction material and has significant impact on the environment, it opens unexplored area of possibilities for improving concrete industry and its reorientation to the sustainability.

Huge potential lies in construction and demolition waste (CDW) which makes 25-30% of all waste generated in the EU. Intensive research activities have been carried out in recycling and reusing of CDW, especially in application of recycled concrete and brick aggregates as replacement of natural aggregates in concrete mixes.

On the other hand, most buildings are ‘sub-standard’ in terms of energy efficiency, comfort and health. Buildings account for the largest share of the total EU final energy consumption producing about 40% of greenhouse gas emissions during their service life.

This paper shows application of recycled aggregate concrete in energy efficient innovative ventilated prefabricated concrete wall panel with integrated Ecose® mineral wool insulation: ECO-SANDWICH®. Special emphasis is given on the research conducted regarding thermal properties of sustainable concrete with high inclusion levels of recycled concrete and brick aggregate, together with sound insulation properties of ECO-SANDWICH® panels, all with respect to similar products.

1. INTRODUCTION

Today’s need for a comprehensive thinking on sustainability is recognized in the civil engineering, especially in concrete industry. Concrete is most widely used construction material and concrete industry is now the largest consumer of natural resources and one of the largest producers of waste. Only in Europe, over 750 million m^3 of concrete is produced annually, which rounds up to 4 tonnes of concrete per capita [1] and therefore has significant impact on the environment.

Therefore, huge potential for the reduction of the environmental impact and the consumption of scarce resources has been identified in the field of concrete industry, especially its reorientation to the sustainability by using construction and demolition waste (CDW). European Commission (EC) identified CDW as a priority waste stream since it represents approximately 49% of the total waste generation in the EU [2]. EU policies are now aimed at significantly reducing the amount of waste generated, through new waste prevention initiatives, better use of resources, and encouraging a shift to more sustainable consumption and production patterns. CDW has large potential for reuse, recycling and other material recovery and therefore EC established the legislative framework for waste management through The Waste Framework Directive (WFD). The Waste Framework Directive (WFD) requires Member States (MS) to take any necessary measures to achieve a minimum target of 70% (by weight) of CDW by 2020 for preparation for reuse, recycling and other material recovery, including backfilling operations using non-hazardous CDW to substitute other materials [3].

On the other hand, Energy performance of buildings is also one of the main topics discussed from EC topics since 1970 and has been widely recognized as an option to decrease energy use. According to Energy Performance of Building Directive - EPBD (2002-91 EC) and its Recast EPBD II (2010-31-EU) [5] buildings account over 40% of total energy consumption in the European Union with the sector expanding and increasing energy consumption. The largest energy saving potential lies in the residential (households) and commercial buildings sector (tertiary sector), where the full potential is now estimated to be around 27% and 30% of energy use, respectively [4]. Therefore, European Union emphasized the need of increasing energy efficiency and the use of energy from renewable sources in the buildings sector [5].

This paper presents the development of the energy efficient wall system ECO-SANDWICH® facade panel as one possible innovative solution that unifies energy efficiency of the buildings and CDW into the one product. Thermal properties of the sustainable concrete with different amount of the recycled concrete aggregate and recycled brick aggregate are given. Also the results of sound reduction index and thermal properties of ECO-SANDWICH® panel are given together with comparison with the similar sandwich products on the market.

2. EXPERIMENTAL PART

For laboratory testing, 4 concrete mixtures were prepared on which a thorough analysis of mechanical and durability properties was performed. The aim of testing was to optimize concrete mixtures for ECO-SANDWICH® wall panel.

In the mixtures, proportions of the recycled aggregate of 40 % and 50 % were varied. All concrete mixtures were produced with cement CEM II A/S 42.5 R. As aggregate, natural sand of the nominal size 0-4 mm from two sources was used: river sand and crushed aggregate together with recycled concrete (RB) and recycled brick (RO) aggregates 4-8 mm and 8-16 mm. For concrete mixtures with 40 % of recycled aggregate, natural crushed aggregate 4-8 mm was also used. Recycled concrete aggregate was produced by crushing laboratory specimens, while recycled brick was produced by crushing waste brick. Except aggregate, proportion of other components was the same in all mixtures: 400 kg of cement, w/c =0.42 and air entraining plasticizer MELCRET SPA 0.7 % per weight of cement.

Table 1: Description of concrete mixtures

Concrete mixture	Type of recycled aggregates used	Replacement of natural aggregates [%]
RB40	Concrete	40
RB50	Concrete	50
RO40	Brick	40
RO50	Brick	50

Since this paper is primarily focused on thermal properties of ECO-SANDWICH® components, and at the end on thermal properties of a precast wall panel as a whole, only the testing method for determining thermal properties and obtained results will be shown.

2.1. Thermal properties of concrete with recycled aggregates

Testing of thermal conductivity was carried out according to HRN EN 12667:2002 and HRN ISO 8302:1998. Among the steady state methods for determining thermal conductivity, the guarded hot plate (GHP) is the most commonly used technique for measuring the thermal conductivity of materials. GHP can be regarded as absolute measurement method, because by measuring the temperature, power of electric energy and thickness the sample thermal conductivity can be calculated. In principle, its operation is based on establishing a steady temperature gradient over a known thickness of a sample and to control the heat flow from one side to the other. Thermal conductivity was determined by the determination of thermal resistance by means of GHP and the known thickness of the specimens used [6].

Thermal conductivity is tested on specimens (concrete with recycled concrete aggregate and concrete with recycled brick aggregate) dimensions 50x50x10 (cm). All specimens were dried on temperature 105 (°C) until constant mass. After achieving constant mass, specimens were conditioned in laboratory conditions of temperature (23±2 °C) and relative air humidity (50±5 %) until testing.

Figure 1: Surface of the specimen with recycled concrete aggregates (left); and with recycled brick aggregates (right)

3. RESULTS OF THERMAL CONDUCTIVITY TESTING

The thermal conductivity of concrete is influenced by the mineralogical characteristics of aggregate and by the moisture content, density, and temperature of concrete. The literature values of thermal conductivity for wet concrete with different aggregate type can be in the range from 1.9 W/mK (basalt) to 3.5 W/mK (quartzite) [7]. Results of testing are shown in the Table 2.

For the concrete density of 1922 kg/m^3 and 2083 kg/m^3 [8], thermal conductivities are 0.99 W/mK and 1.18 W/mK, respectively (for dry concrete made with limestone aggregates). According to [9], thermal conductivity is 1.13 W/mK for the concrete with the density of 2000 kg/m^3. It can thus be concluded that the concrete containing recycled concrete and recycled brick aggregates have 13 - 27 % and 29 - 40 % lower thermal conductivity than the reported literature values for the dry concrete with approximately the same density. It has to be noted here, that concrete which is made with natural aggregates with the density of 2400 kg/m^3 and is usually being used for this kind of applications in Structural Concrete Insulated Panels (SCIP's) has the thermal conductivity of 2.00 W/mK [10]. Layer of thermal insulation (Ecose® based mineral wool) has value of thermal conductivity λ = 0.034 W/mK.

Table 2: Results of the thermal conductivity testing

Specimen	**Density [kg/m^3]**	**Mean thermal conductivity λ at 10 °C, in dry state [W/mK]**
RB40	2064.6	0.867
RB50	2105.0	0.858
RO40	1912.7	0.703
RO50	1971.0	0.746

4. ECO-SANDWICH® FAÇADE SYSTEM

One of the possible applications of recycled aggregate in concrete is in the industry of prefabricated elements.

The ECO-SANDWICH® wall system is innovative prefabricated wall panel with integrated core insulation allowing very low energy design and retrofit of buildings [11, 12]. It consists of two precast concrete layers interconnected through stainless steel lattice girders, Figure 2. The inner (load bearing) layer of the ECO-SANDWICH® is made of recycled concrete aggregates while the outer façade layer is made of recycled brick aggregates. After mechanical and durability testing [13], it was decided that inner layer of ECO-SANDWICH® panels will be made with 50% of recycled concrete aggregates while the outer façade layer will be made with 50% recycled brick aggregates. Layer of thermal insulation 20 cm thick is free formaldehyde Ecose® based mineral wool. To prevent possibility of water vapour condensation, layer of ventilated air is placed between layer of thermal insulation and outer façade layer.

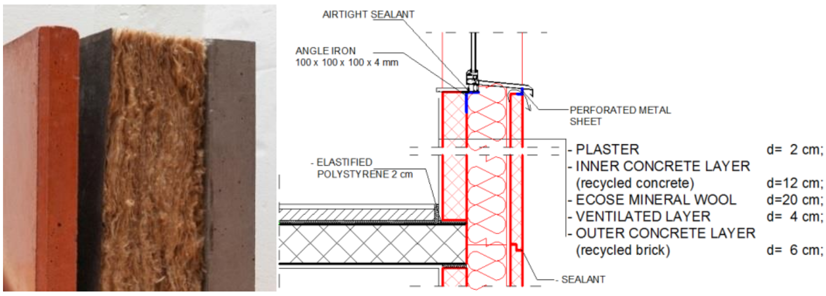

Figure 2: ECO-SANDWICH® wall system

The ECO-SANDWICH® has a vast potential to substantially improve energy performance of the deteriorating building stock thus facilitating a move towards reaching the EU's 20-20-20 goals by 2020. The ECO-SANDWICH® helps to follow waste hierarchy by using recycled CDW and recycled materials used in the production of Ecose® based mineral wool. Being harmonized with both Energy Performance of Building Directive - EPBD (2002-91-EC), its Recast EPBD II (2010-31-EU) [5] and EU Waste Framework Directive (2008/98/EC) [3], the ECO-SANDWICH® wall system is expected to facilitate the implementation of both legislations by providing a market for recycled CDW and by substantially improving the energy balance of the existing as well as new buildings.

It is also widely accepted that only manufacture in controlled factory conditions can achieve the defect free, waste free quality product and only factory conditions are likely to provide the sort of safe, healthy, pleasant working environment.

4.1 Thermal properties of ECO - SANDWICH® and comparison with similar precast wall panels

Thermal conductivity values of ECO-SANDWICH® concrete layers with recycled aggregates are shown in the Table 2. Thermal properties of the ECO-SANDWICH® panel and similar precast wall panels are determined by the U – value. The U – value is calculated according to HRN EN ISO 6946:2008 and HRN EN ISO 13789:2008 for known material properties and thickness of every single layer of the precast wall systems.

In Table 3 are shown layers and its dimensions for ECO-SANDWICH® and similar products. In the Figure **3** are shown U – values of ECO - SANDWICH® and other wall panels described in the Table 3.

Table 3: List of compared sandwich wall panels

Name of precast wall panel	**Layers**	**Thickness of layer [cm]**
ECO - SANDWICH®	Concrete with recycled concrete aggregates	12
	ECOSE® mineral wool insulation	20
	Ventilated air	4
	Concrete with recycled brick aggregate	6
Structural Concrete Insulated Panel 1 (SCIP 1)	Concrete	6
	Expanded Polystyrene (EPS)	20
	Concrete	6
Structural Insulated	Aluminium	0.1

Panel 1 (SIP 1)	Extruded Polystyrene (XPS)	20
	Aluminium	0.1
Structural Insulated Panel 2 (SIP 2)	Steel sheet	0.1
	Mineral wool	20
	Steel sheet	0.1

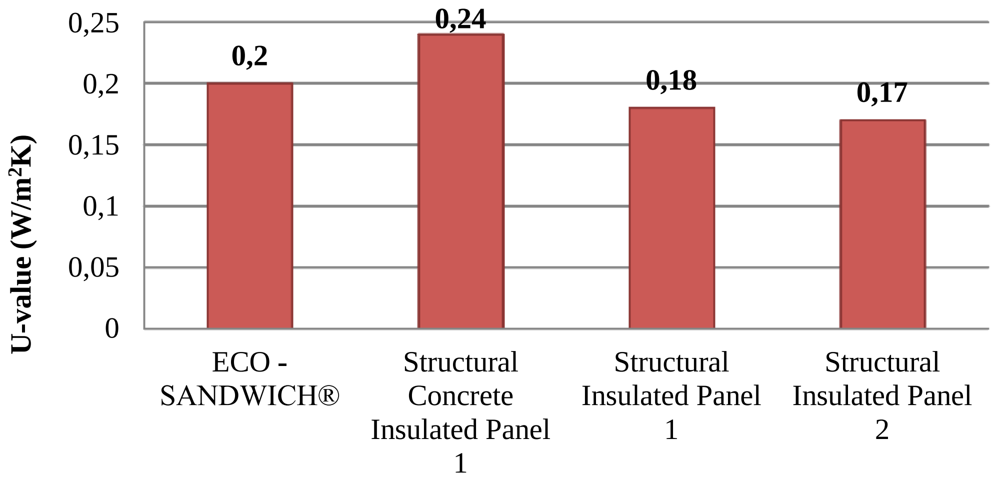

Figure 3: Comparison of U – values for different sandwich wall panels

4.2 Sound and sound insulation

In buildings, except ultimate limit state (ULS) defined by mechanical properties, the serviceability limit state (SLS) also has to be satisfied and guaranteed. Besides other properties, SLS is defined by thermal and sound insulation properties.

Sound is every mechanical deformation in the elastic medium that is variable in time. Regarding the sound properties of construction elements, and structure as a whole, users ofthe structure have to deal with a noise problem. Noise is every sound that is considered as unacceptable, annoying or interfering. The only difference between the sound and noise is completely subjective. Physically they are the same, so it is impossible to define the noise objective [14].

Exposure to the high level of noise can cause hearing impairment, even the hearing loss. Exposure to the low level of noise has psychological effects to the people: lack of concentration, attention deficit, disruption of sleep and rest, inability to work, etc.[14]. Therefore, sound insulation of construction and its elements has to be taken in consideration.

Sound insulation of construction wall elements is defined as a transmission loss or sound reduction index R. The transmission loss R is a measure of the effectiveness of the construction elements which presents a barrier restricting the passage of sound. The transmission loss varies with frequency and the loss is usually greater at higher frequencies. The higher transmission loss of a wall, the better it functions as a barrier to the passage of unwanted noise. There are two types of sound insulation in buildings: airbone and impact. Airbone sound insulation is used when sound produced directly into the air is insulated and it is determined by using the sound reduction index. Impact sound insulation is used for floating floors and it is determined by the sound pressure in the adjacent room below.

Since this paper is presenting energy efficiency aspects of recycled aggregate concrete and example of its usage in an innovative precast wall panel, airbone sound insulation of a precast wall panel through its sound reduction index R will be shown.

4.3. Sound reduction index of ECO - SANDWICH® and comparison to similar sandwich wall panels

Sound reduction index of ECO–SANDWICH® and three similar products available on the market have been calculated according to national standard HRN EN 12354 based on known material properties and dimension (thickness) of every single layer of the sandwich wall panel. In computer programme, all precast wall panels were simulated as classic barrier without openings.

Figure 4 shows the results of sound reduction layer index R of ECO – SANDWICH® and three other sandwich wall panels.

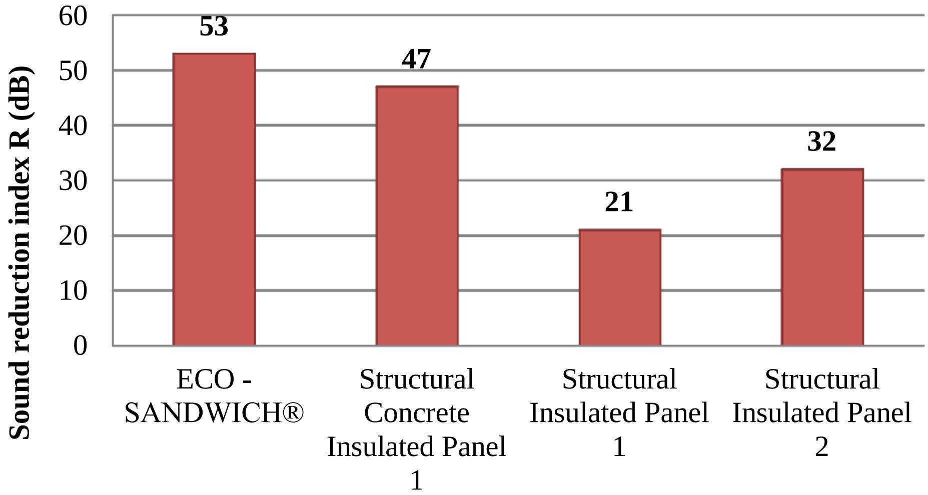

Figure 4: Sound reduction index of ECO - SANDWICH® and similar sandwich products

5. CONCLUSIONS

Most studies recommend the limit use of 30 % of recycled aggregate in the concrete. In this research, it is shown that both, recycled brick and recycled concrete can be successfully used for high-grade application in the frame on energy efficiency. When comparing results of testing thermal properties, it can be concluded that concrete containing recycled concrete and recycled brick aggregates have 13 - 27 % and 29 - 40 % lower thermal conductivity than the reported literature values for the dry concrete with approximately the same density. By this reason (as shown in Figure 3), ECO-SANDWICH® has 16.6% lower U-value than similar precast concrete wall panels on the market. ECO - SANDWICH® has 10 – 15% higher U – values than compared with metal sandwich panels, but it is necessary to emphasize importance of thermal mass in terms of energy performance of buildings. Concrete sandwich panel has higher thermal mass than metal sandwich panel and that results with 11 % less energy needed for cooling and 22 % less energy needed for heating in buildings built with SCIP compared to buildings built with metal SIP. With this research, it was shown that by using recycled concrete and recycled brick as recycled aggregate in the concrete mixes, sound insulation of precast wall systems can be improved. The ECO-SANDWCH® panel reduces transmission of sound energy into buildings for 53 dB, which is more than can be achieved with similar compared sandwich wall panels on the market (shown in Figure 4).

With presented sound and thermal insulation properties and with controlled manufactured production, an innovative energy efficient precast panel system ECO-SANDWICH® can compete to similar sandwich wall panel on the market, showing a good example of using recycled aggregate in modern concrete industry.

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