

Structural Concrete Insulated Panels (SCIP's) has the thermal conductivity of 2.00 W/mK (Willems 2006).

3.5 Water vapour diffusion coefficient

Testing of water vapour diffusion coefficient was carried out according to HRN EN ISO 12572:2002, conditions C („wet cup test“) – Hygrothermal performance of building materials and products - Determination of water vapour transmission properties.

For testing, 5 specimens of thickness 50 mm and diameter 125 mm were prepared. Until start of testing, specimens were kept at the temperature of 23 ± 2 °C and relative humidity of 50 ± 5 %.

Table 5: Results of testing water vapour diffusion coefficient

Specimen	Relative resistance to water vapour diffusion, s_d (m)	Water vapour diffusion coefficient, μ
RB40	1,32	26
RB50	1,77	37
RO40	0,88	18
RO50	1,40	29

From the Table 5, it can be seen that concrete produced with recycled concrete and recycled brick aggregates has lower water vapour diffusion coefficient than the literature values for concrete with the density of 2000 kg/m^3 , which has $\mu = 60/100$, in wet and dry state, respectively (Willems 2006). It can be concluded that water vapour diffusion coefficient for concrete is from 38 to 70% lower compared to the literature values for similar wet concrete.

4. ANALYSIS

When comparing results of testing concrete produced in similar conditions, it can be concluded that increase of the recycled brick amount from 40 % to 60 % decreases compressive strength for approximately 10 %. For recycled concrete, there is a similar trend for 28-day compressive strength, but concrete with 60 % recycled aggregate has had faster strength development.

For aggregate obtained from recycled concrete, it is however very important interfacial transition zone and composition of the old concrete. When observing results of testing concrete with 50 % recycled aggregate, influence of the air content on the results of testing compressive strength is obvious. Concrete with 50 % of recycled concrete aggregates has the lowest air content and consequently the highest compressive strength. Concrete with 50 % recycled brick has higher air content than

concrete with 40 % and 60 % recycled brick and that causes lower compressive strength.

Obviously, crucial influence on the results of testing compressive strength and other concrete properties has preparation of the concrete mixtures and amount of the chemical admixture. The highest modulus of elasticity in the age of 3 and 28 days has concrete with 50 % recycled concrete, the same as it has the highest compressive strength. In general, concrete with recycled brick has lower values of modulus of elasticity. By increasing amount of recycled brick, modulus of elasticity decreases. Values of flexural strength are approximately the same for all concrete mixtures. The highest value was obtained for concrete containing 50 % of recycled concrete, as for compressive strength. Regarding durability properties, it can be concluded that all concrete types, with recycled concrete and recycled brick, satisfy requirements for class exposures XF1, XF2, XF3 and XF4. Higher coefficient of gas permeability had concrete produced with recycled concrete aggregates. Based on the results of testing, it can be concluded that resistance to chloride penetration is unsatisfactory and that tested concrete types would not be suitable for structural elements in marine environment or it should be additionally protected. All results of testing are shown in Table 6.

Table 6: Results of testing concrete with recycled aggregate

Property	Concrete mixture					
	Recycled concrete			Recycled brick		
	RB40	RB50	RB60	RO40	RO50	RO60
CONSISTENCY, slump (mm)	S3	S2	S3	S3	S3	S3
COMPRESSIVE STRENGTH, 28 day (MPa)	44.3	51.2	42.8	44.3	39.7	40.7
MODULUS OF ELASTICITY, 28 days (GPa)	27.4	33.8	28.0	21.3	18.2	15.5
FLEXURAL STRENGTH, 28 days (N/mm ²)	5.8	6.4	5.4	5.8	5.9	5.2
COEFFICIENT OF CAPILLARY ABSORPTION (kg/m ² √h)	1.31	1.09	1.92	0.49	1.12	0.50
CHLORIDE MIGRATION COEFFICIENT D _{nssm} (×10 ⁻¹² m ² /s)	49.92	11.15	30.67	21.01	16.66	21.21
FREEZE-THAW RESISTANCE (%)						
28 cycles (max. 25 % for XF1)	0.2	1.8	0	7.2	6.0	6.5
56 cycles (max. 15 % for XF3)	1.0	*	1.3	4.5	*	5.4
FREEZE-THAW RESISTANCE - SCALING (kg/m ²)						
28 cycles (≤ 0.5kg/m ² for XF1)	0.07	-	0.07	0.13	-	0.13
56 cycles (≤ 0.5kg/m ² for XF3)	0.08		0.08	0.13		0.14
AVERAGE WATER PENETRATION DEPTH (mm)	-	14	-	14	24	-

Property	Concrete mixture					
	Recycled concrete			Recycled brick		
	RB40	RB50	RB60	RO40	RO50	RO60
COEFFICIENT OF GAS PERMEABILITY ($\times 10^{-17} \text{ m}^2$)	-	14.44	-	-	8.83	-
RAPID AIR TEST, SPACING FACTOR (mm) (<0.2 mm) SPECIFIC SURFACE (mm^{-1}) (>25 mm^{-1})	0.104 35.34	0.159 29.90	-	0.075 38.42	0.114 26.13	-
MEAN THERMAL CONDUCTIVITY at 10 °C, in dry state (W/mK)	0.867	0.858	-	0.703	0.746	-
WATER VAPOUR DIFFUSION COEFFICIENT, μ	26	37	-	18	29	-

*Not measured

4.1 ECO-SANDWICH[®] wall system

One of the possible applications of recycled aggregate in concrete is in industry of prefabricated elements. Hereafter will be shown application of RAC in innovative wall panel system called ECO-SANDWICH[®] (Banjad Pecur 2012a, Banjad Pecur 2012b).

The ECO-SANDWICH[®] wall system is prefabricated wall panel with integrated core insulation allowing very low energy design and retrofit of buildings. It consists of two precast concrete layers interconnected through stainless steel lattice girders, Figure 3. 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.



Figure 3: 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 Ecosse[®] based mineral wool. Being harmonized with both Energy Performance of

Building Directive - EPBD (2002-91-EC), its Recast EPBD II (2010-31-EU) and EU Waste Framework Directive (2008/98/EC), 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. In order to maximise usage of recycled CDW without the reduction of mechanical and durability properties, concrete mixtures need to be optimized.

It is also widely accepted that only manufacture in controlled factory conditions can achieve the defect free, waste free quality production and to provide the sort of safe, healthy, pleasant working environment that will be acceptable to the young talented, skilled workforce that the industry needs. These are some of the advantages of prefabricated systems, which can be also recognized in the better quality standard and performance guarantee that is increasingly being demanded from architects and civil engineers.

5. CONCLUSIONS

In order to achieve the best ecology-to-quality ratio considering materials, during the presented research, concrete mix proportioning was optimized in order to maximise usage of recycled CDW without the reduction of mechanical and durability properties. The paper shows results of testing mechanical and durability properties of the concrete mixtures produced with different amounts and different types of the recycled aggregate, together with thermal properties and water vapour resistance respectively. The quality of recycled aggregate directly depends on the quality and composition of CDW. Composition and quality of CDW have influence on the quality of recycled aggregate produced from waste. Most studies recommend a limit of 30 % of recycled aggregate.

This research shows that both, recycled brick and recycled concrete can be successfully used for high-grade application even in amount of 60 % of recycled aggregate. For specific purpose, it is however necessary to carry out a preliminary testing of the relevant concrete properties to make decision on optimum recycled aggregate amount in concrete. Additionally, it was shown that recycled aggregate concrete satisfies requirements for freeze-thaw resistance and can be successfully applied in outer concrete elements. However, certain precaution is necessary if using recycled aggregate in harsh environment. In these cases, it is recommended to use lower amount of recycled aggregate and to prove by testing that concrete satisfy prescribed requirements.

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