Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Sustainability of concrete elements from concrete with ternary binders

Vlastimil Bilek[1], Ctislav Fiala[2]

[1]*ZPSV a.s., Trebizskeho 207, 687 24 Uhersky Ostroh,Czech Republic, e-mail: bilek@zpsv.cz*
[2]*Faculty of Civil Engineering, Czech Technical University Prague,Thakurova 7, 166 29 Prague 6,Czech Republic, e-mail: ctislav.fiala@fsv.cvut.cz*

ABSTRACT

Concrete with optimum combinations of two mineral admixtures (with ternary binders) can show better early strengths than concrete with one of the admixtures only. This can be considered as a synergy. The synergy is not connected with the early strength only; this can even be more important in terms of durability of concrete, especially in terms of frost resistance. The ternary binders enhance frost resistance in comparison with binary binders.

The paper shows a development of ternary binders from fly ash and limestone or from ground granulated blast furnace slag and limestone. Concrete elements are designed from the concrete with ternary binders instead of the concrete with Portland cement only and they are produced in different concrete plants in the Czech Republic. Their use is evaluated from the point of view of Life Cycle Assessment.

Keywords. Ternary binders, LCA, fly ash, limestone, durability

INTRODUCTION

Ternary binders. The sustainability of concrete and concrete structures is also affected by the reduction of the amount of consumed cement and the use of mineral admixtures, especially waste materials. Usually, concretes with mineral admixtures show some worse properties than those with Portland cement only.

A beneficial effect of ternary binders was a number of times reported, especially for pastes and mortars, for example – Carrasco M.F. et al (200 3), Badanoiu, A. et al. (2006), Kadri, et al. (2010). These authors especially print out a higher early strength of mixtures with ternary binders (CEM I + GGBFS + L). All of them explain this phenomenon by 1) a better (quicker) hydration of especially calcium alumosilicate phases and 2) grains of admixtures acting as nuclei for the precipitation of hydration products. Also the third reason can be important – the better grading curve of fine materi als and a better filling of space between fine grains of cement and admixtures.

A very detailed study of an influence of ternary binders on the hydration of Portland cement was performed by De Weerdt, K., Kjellsen, K.O. et al. (2011) and De Weerdt, K., Ben Haha M. et al.(2011). In accordance to their conclusions, the addition of limestone to portland cement promotes the formation of calcium aluminate hydrates but these reactions are limited due to the limited aluminate content in clinker. But supplementary cementitious materials – for example fly ash – can provide additional alumin ates and amplify the benefitial effect of limestone. The real synergy occurs in the ternary blends.

Bilek (2012) shows that the synergy effect can also be found in the case of concrete – not only mortars. But in accordance to these papers some more important properties than early strength are recorded – a better frost resistance a nd a lower risk to alkali-silica reaction. These properties make ternary binders very convenient for concrete technology. Concretes with ternary binders can replace former concretes or they are designed for the production of new elements.

Life Cycle Assessment. The life cycle assessment (LCA) methodology is an iterative assessment method. It includes several steps covering (a) definition of the goal and scope, (b) inventory analysis, (c) impact assessment and (d) interpretation of results. These particular steps are in a state of mutual interaction. LCA methods and models should take into account all important environmental impacts within the whole life cycle ("from cradle to grave") of a concrete product (element, structure, etc.) The typical life cycle of a concrete product should cover all life stages, from raw material acquisition, through construction and operation, up to demolition and reuse of the materials or waste disposal (Hájek, P., Fiala, C., Kynčlová, M. 2011, Hájek, Fiala, Kynčlová, 2012).
All the material and energy flows (inputs and outputs) are balanced and quantified - i.e. consumption of raw materials, products and by-products, auxiliary materials, energy, water and transport, emissions, by-products and waste from manufacturing processes. On the basis of the LCA some environmental indicators: primary energy consumption, global warming potential, raw materials consumption, water consumption, photochemical ozone creation potential, acidification potential etc. are specified. Only the first two of them are presented and discussed in this paper.

Case studies. This paper deals with three different case studies of the use of concrete with ternary binders

Firstly, LCA is applied to the production of the same concrete elements in the same concrete plant. This means that only the effect of utilisation of ternary binders is evaluated. Concrete is considered to havo the same strength class and the same workability.

Secondly, the production of special concrete elements – console platform block – was moved from the concrete plant D to concrete plant N. At the same time, the concrete with ternary binder was designed for concrete plant N. And what´s more – concrete in D was dry while the new concrete in N is designed as self compacting concrete. LCA evaluated if it was better to transport concrete from D to building site (250 km) or if it is better to produce these elements in N (distance from building site is 50 km).

Thirstly, a new element – a thin balcony railing – was designed from High performance fiber reinforced self comcpacting concrete (HPFRSCC) using ternary binder. LCA evaluates the effect of this change.

CASE STUDY 1 - EXCHANGE OF CONCRETE

Composition of former concrete and newly designed concrete with ternary binder are shown in Table 1.

Table 1. Composition of original and new-designed concrete

	V1 original	**V2** new
CEM I 42.5 R Mokrá	450	340
Fly ash	0	85
Ground limestone	0	30
water	180	180
mix of aggregates	1750	1720

The newly designed concrete is a result of optimisation of the composition. Some results of the optimisation of new mixture can be seen in Figure 1 and Figure 2.

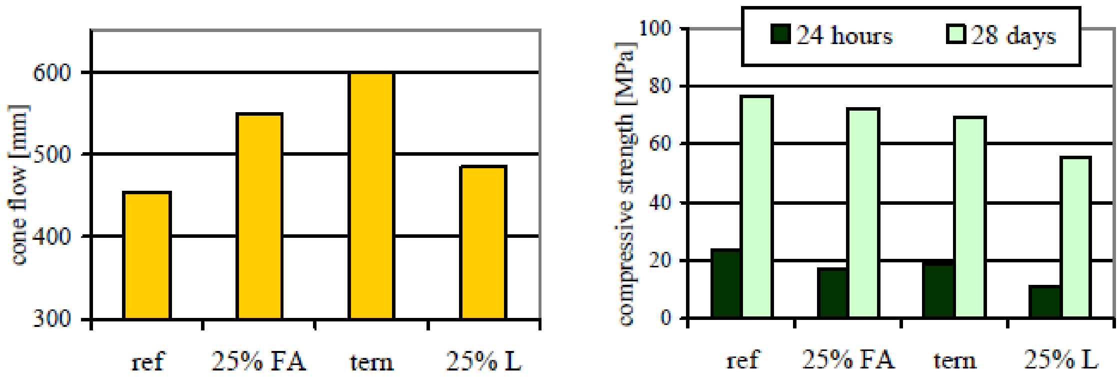

Figure 1. Workability and compressive strength of reference concrete, concretes with one admixture and concrete with ternary binders (see Table 1)

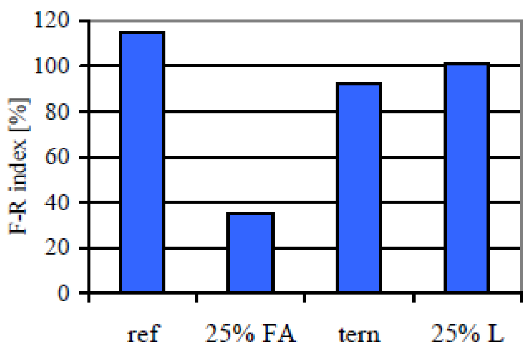

Figure 2. Frost resistance of reference concrete, concretes with one admixture and concrete with ternary binders (see Table 1)

The figures show workabilities and compressive strengths for original concrete, original concrete with substitution of 25% of cement with fly ash, with mixture fly ash and limestone and with ground limestone. The newly designed concrete shows the best workability from all the discussed concretes and also the highest early strength except the concrete without admixtures. Very important is the comparison of frost resistance of the concretes in terms of frost-resistance (F-R) index – it means ratio *bending strength of frosted beams / bending strength of reference beams*. The frost resistance of concrete with 25% of fly ash is very low, while the frost resistance of concrete with ternary mixture is excellent, see also Bilek (2012) and Bilek (2013). All of the presented results show that concrete with ternary binder is an optimum choice from the point of view of mechanical properties (and also economy). The results of LCA are presented in figure 3 and 4 in terms of primary raw materials consumption and global warming potential.

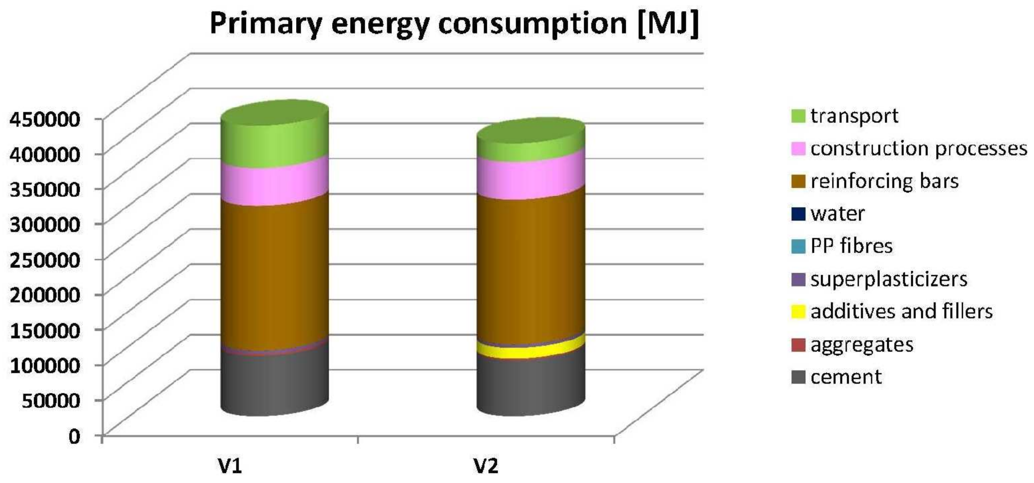

Figure 3. LCA of reference concrete and concrete with ternary binder (see Table 1) from point of view of primary raw materials consumption

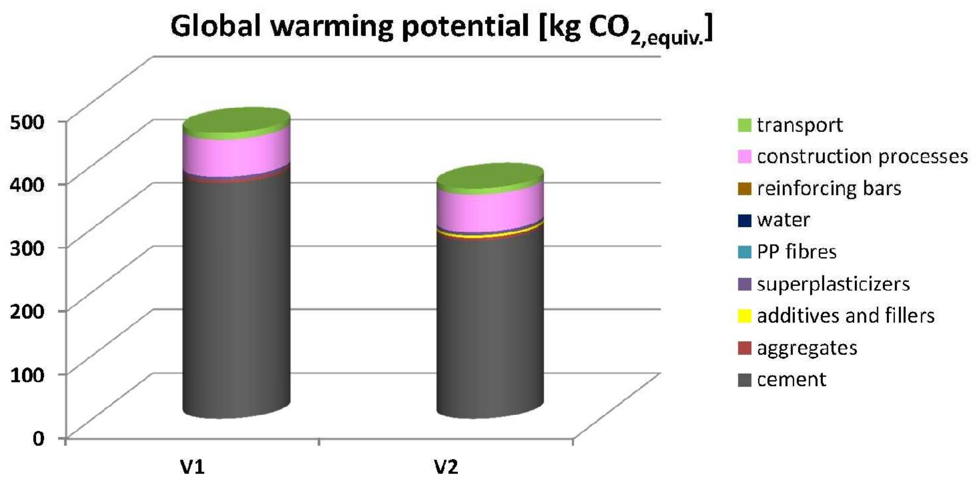

Figure 4. LCA of reference concrete and concrete with ternary binder (see Table 1) from point of view of global warming potential

It can be seen that the use of concrete with ternary binders brings benefit in both of these properties. This is a result of especially Portland cement dosage reduction.

CASE STUDY 2 - EXCHANGE OF CONCRETE AND CONCRETE PLANT

In this case the old – original – concrete with wor se workability was replaced by self compacting concrete containing ternary binder – a m ix of ground granulated blast furnace slag (GGBFS) and ground limestone (L). The composition of the original concrete and the newly designed concrete with a ternary binder are shown in Table 2, together with the transport distance for raw materials and for concrete elements – it means, for example, distances of concrete plants from cement plant or distances of concrete plants from quarries… The total amount of 200 elements was cons idered.

Table 2. Composition of original and new-designed concrete for case 2

	V 1 (original)		**V 2** -new	
	material	dist.	material	dist.
	[kg]	[km]	[kg]	[km]
CEM I 42.5 R Mokrá	390	50	360	250
GGBFS (380 m^2/kg)	0	-	130	300
Ground limestone (280m^2/kg)	0	-	130	200
water	150		195	
mix of aggregates	1750	30	1455	15
workability	20-30sVeBe		cone flow 650 mm	
Distance from site place	300 km		50 km	

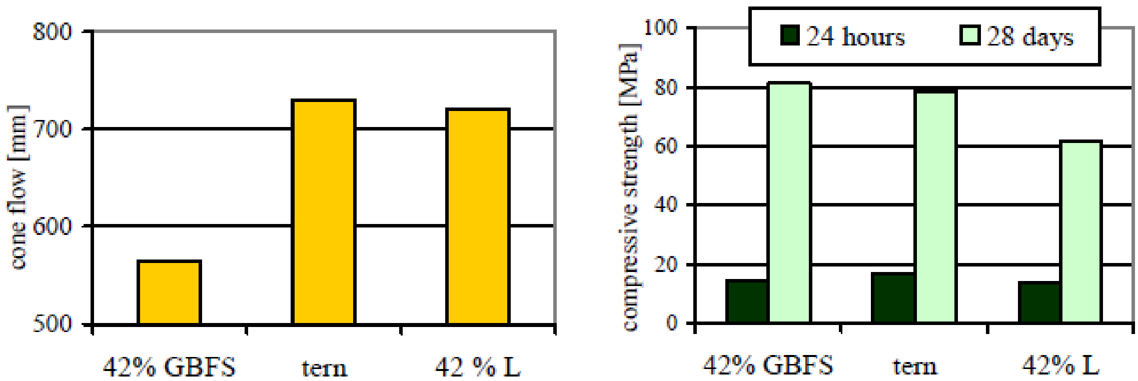

Figure 5. Workability and compressive strength of concretes with one admixture and concrete with ternary binders (see Table 2)

As in the previous case, the technological and mechanical properties of concretes with ternary binders are better than those of concrete with binary binders – Figure 5. The frost resistance of concrete with ternary binder is excellent (the F-R index is 94%). In contrary to the original concrete, which had bad workability, the new concrete is self compacting which means better working conditions for workers and also a lowering of human work. Apart from this, also LCA environmental indicators are better – see Figures 6 and 7.

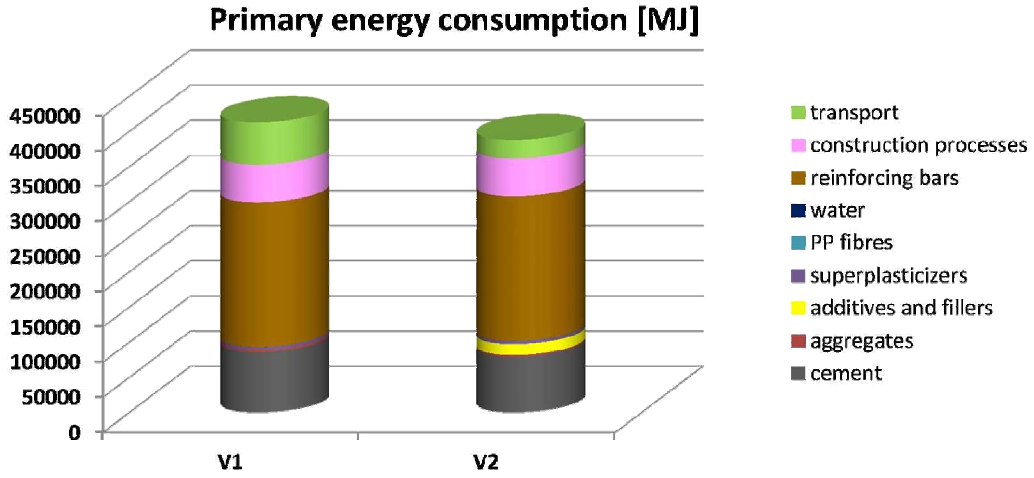

Figure 6. LCA of reference concrete and concrete with ternary binder (see Table 2) from point of view of primary energy consumption

Both of the indicators – primary energy consumption and global warming potential - show, that these two concretes are nearly equivalent. The difference is especially in transport. The distances from the cement plant and from the admixtures suppliers are higher from concrete plant N (V2) than D (V1), but distance from N to the building site is lower than from D. The lowering of transport distance of concrete elements shows ecological benefits.

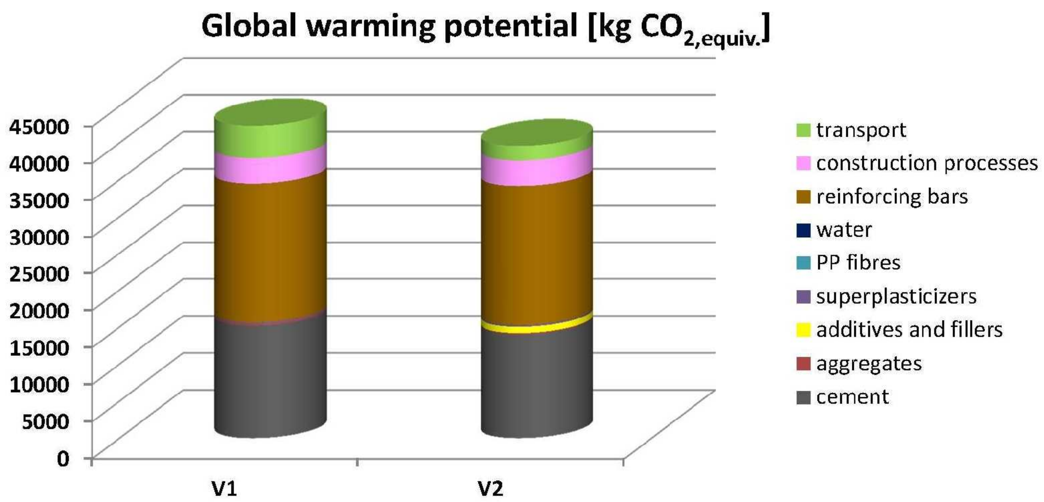

Figure 6. LCA of reference concrete and concrete with ternary binder (see Table 2) from point of view of global warming potential

CASE STUDY 3 – MODIFICATION OF THE SHAPE OF THE ELE MENT AND USE OF HIGH PERFORMANCE CONCRETE

One of commonly made concrete elements is balcony railing. These railing s were originally made from usual concrete (C 25/30 up to C35/45). The railing depth was 80 mm and the mass of one element was 900 kg. A new shape was designed – the depth of railing is only 40 mm, while the depth around the circumference is increased by 100 mm. The traditional reinforcement is replaced by polymer fibers (only around the circumference are steel bars). Self compacting fibre reinforced concrete C 60/75 with ternary binder is used for the new barriers production – see Table 3. The distances to the building site are the distances to the nearest big city where the elements are delivered. It is supposed that 40 elements are transported to the building site.

Table 3. Composition of original and new-designed concrete for case 2

	V 1		V 2		V 3	
	C 35/45	dist.	C 60/75	dist.	C60/75	dist.
	kg	km	kg	km	kg	km
CEM I 42.5 R Mokrá	420	50	465	60	440	250
Metakaoline	0		35	200	35	150
GGBFS 380 m^2/kg	0		150	200	100	300
Stone filler	250	70	50	80	-	
Ground limestone	0		0		130	200
water	190		215		215	
Mix of aggregates	1460	30	1440	10	1450	15
fibres	0		2.5		2.5	
Mass of steel reinfor.	55 kg		12 kg		12 kg	
Distance to site place	60 km		80 km		35 km	

Both of HPFRSCC show a good workability, which is affected by metakaoline. This admixture is added not for their pozzolana activity but for the beneficial effect on workability and also on frost resistance (better than microsilica). Compressive strengths of both the concretes at the age of 28 days are above 90 MPa. Figure 7 shows production of the railings and Figure 7 and Figure 8 show some LCA results are presented.

Figure 7. Production of balcony railings from HPFRSSC with ternary binders

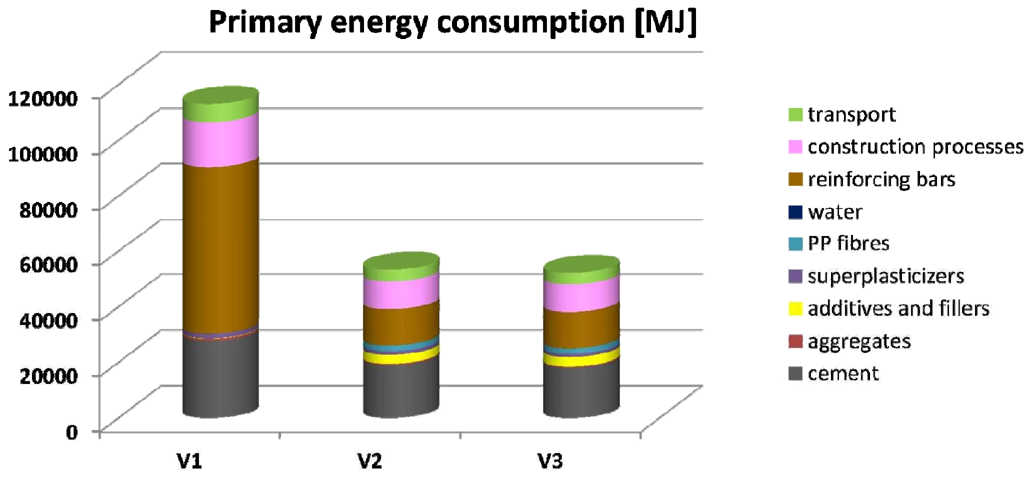

Figure 8. LCA of reference concrete and HPFRSCC with ternary binder (see Table 3) from point of view of primary energy consumption

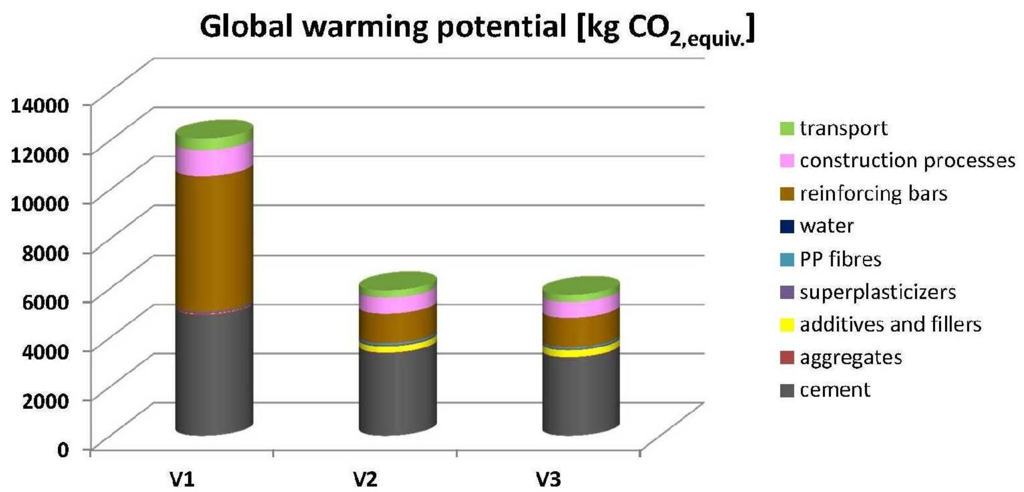

Figure 9. LCA of reference concrete and HPFRSCC with ternary binder (see Table 3) from point of view of global warming potential

A cement dosage reduction and a reduction of mass of steel bars have the most significant effect on both of the discussed parameters. Also the transport of light elements is better – nearly twice more elements can be transported in one car.

CONCLUSION

The concretes with ternary binders were found as the most optimum choice of sustainable concrete. In comparison with concrete with binary binders (with only one admixture) they show better workability, better early and good long-time strengths, good frost resistance and also a lower risk of alkali-silica reaction (Bilek et al., 2012).

The presented case studies show an effect of these optimum concrete with ternary binders on the sustainable development of concrete structures. LCA shows that there can be found some benefits from the point of view of primary energy consumption and global warming potential as well as from the point of view of raw materials consumption and other environmental impacts which weren't discussed here. Especially the design of high performance concrete with this type of binder can bring a huge positive effect. The LCA also shows some importance of concerning distances of concrete plants from the building site and from the producers of cement and admixtures.

ACKNOWLEDGEMENT

This work has been undertaken with financial support from research program Alfa 3 of TACR , project TA03010501 and from Grant CTU SGS11/103/OHK1/2T/11. All support is gratefully acknowledged

REFERENCES

Badanoiu, A., Ghizdavet, Z., Stoleriu, S.(2006) Ternary blended binders with limestone filler and active mineral admixtures, *Proc of Int. Conf. Ibausil 2006*, Weimar, Germany, pp.1-0227 – 1-0234

Bilek, V. sr., Bilek, V.jr., Krutil, K., Krutilova, K. (2012) Some aspect of durability of concrete with ternary binders, *Proc of 8th CCC Durability of concrete*, Plitvice Lakes, Croatia, pp. 359-364, ISBN 978-953-7621-14-8

Bilek, V. (2012) Development of concrete with ternary binders, *Proc. of 12th Int. CANMET Conf. On Recent advances in concrete technology and sustainability issues*, *Supplementary papers*, Prague, Czech Rep., pp.547-562, ISBN 978-0-9916737-1-1

Bilek, V. (2013) Some aspects of durability of concrete with ternary binders, *Proc of Int. conf. ACCTA 2013*, Johenesburg, South Africa, in print.

Carrasco M.F, Menéndez G, Bonavetti V, Irassar E.F. (2003) Strength development of ternary blended cement with limestone filler and blast furnace slag, *Cement and Concrete Composites* 25, (2003) p.61-67

De Weerdt, K., Kjellsen, K.O., Sellevold, E., Justnes, H. (2011a) Synergy between fly ash and limestone powder in ternary cements, *Cement and Concrete Composites* 33, (2011) pp.30-38

De Weerdt, K., Ben Haha, M., Le Saout, G., Kjellsen, K.O., Justnes, H., Lothenbach B. (2011b) Hydration mechanismus of ternary Portland cements containing limestone powder and fly ash, *Cement & Concrete Research* 41, (2011b) pp.279-291

Hájek, P., Fiala, C., Kynčlová, M.(2011) Life Cycle Assessment of Concrete Structures – A step towards environmental savings, *Structural Concrete, Journal of the fib*, Volume 12, Number 1, 2011, ISSN 1464-4177

Hájek, P., Fiala, C., Kynčlová, M. (2012) Life-cycle assessment of RC structures in Czech regional conditions, *IALCCE 2012*, Wien, Austria, 2012, p. 197, ISBN 978-0-415-62126-7, eBook ISBN 978-0-203-10336-4