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Ferromolybdenum slag as valuable resource material for the production of concrete blocks

Luc BOEHME[1], Dirk VAN DEN HENDE[2]

[1] Department of Construction, K.H.B.O.- IW&T, 8400 Oostende
[2] Henloton, 9080 Lochristi

luc.boehme@khbo.be, dirk@vandenhendebeton.be

Abstract

This paper discusses a case in which ferromolybdenum slag is successfully used as aggregate to produce concrete "R-blocks". Experiments were carried out to define the optimum mix compositions taking into account mechanical properties, texture of the block and technical aspects of the production. The main goal was to achieve a particle size distribution of the ferromolybdenum slag being similar to that of the natural aggregates used conventionally in concrete blocks. To obtain a BENOR certification label, the test results had to comply with the European and Belgian standards on masonry blocks in concrete. The environmental aspects were also taken into account. The results indicate that ferromolybdenum slag can be used as aggregate in R-blocks, which are currently in production.

Introduction

Concrete blocks are one of the common building materials used in the construction of walls. Such blocks are precast concrete products, implying that the blocks are manufactured before they are taken to the construction site. These concrete blocks are designed and casted with one or more perforations to reduce the weight and to improve the insulation capacity. For applications in masonry foundations, concrete blocks are usually produced without perforations.

Secondary aggregates have started to substitute for natural aggregates (gravels) used in precast concrete production due to two main reasons. Firstly, natural aggregates are becoming scarce and more expensive. Secondly, there is an urgent need to reduce the waste level produced by several industries. The current Flemish law "VLAREA – *Vlaams Reglement Inzake Afvalvoorkomingen –Beheer*",[1] which focuses on preserving the environment, allows the reuse of certain waste streams in specific construction applications.

In developing and industrial countries, large amounts of industrial waste or by-products are stored or landfilled every year. The recycling of these residues is becoming an increasing interest worldwide due to the high environmental impact of

cement and concrete industries (see also Session 1 in this Symposium Book).[2,3] Besides, high amounts of aggregates are needed for the production of concrete. Nearly all natural aggregates come from excavation of riverbeds or quarries, leaving the open spaces with deep holes and damaging the ecosystems. Until recently it has been cheaper to landfill wastes than to recycle them. As the natural aggregates are becoming scarce and expensive, and as governmental pressure is increasing to find ecological solutions for waste residues, we must find opportunities to transfer these residues into valuable resources for applications such as construction materials.

Researchers have been investigating the properties of concrete containing some by-products and wastes such as granulated blast-furnace slag (GBFS), fly ash (FA), bottom ash (BA), silica fume (SF), waste glass (WG) as mineral addition, aggregate replacement or binding material.[4-11] Boehme *et al.*[12] investigated the use of mixed construction and demolition waste (mCDW) as a potential aggregate substitution for natural aggregates in the production of concrete blocks. It was concluded that a high fraction of the natural aggregates could be replaced by mCDW. In non-perforated blocks the replacement fraction was up to 95 wt% while in perforated ones it could go up to 75 wt%.

Poon *et al*.[13,14] showed that it was feasible to produce paving blocks using crushed clay brick (up to 25 wt%). Yüksel and Bilir[15] investigated the use of industrial by-products to produce plain concrete elements. In their work briquettes were made with bottom ashes and granulated blast furnace slags. In both of these studies the employed concrete mixtures differ substantially from the one described in this paper. Conventional mix proportions with a high amount of cement (363 kg/m^3) and a W/C-ratio of 0.53 were used. The mix proportions that Poon *et al*.[13,14] used for the paving blocks contained even higher contents of cement (670 kg/m^3) at W/C ratios up to 0.49. The concrete mixtures of the R-blocks containing FeMo-slag, which is the topic of this paper, contain lower contents of cement (160 to 200 kg/m^3) at a W/C ratio between 0.45 and 0.50.

The negative impacts of the concrete industry on the environment can be reduced by producing more durable concrete with effective use of resources. Industrial by-products and solid wastes can be used for this purpose. According to the industrial ecology concept, a by-product of one industry may be a raw material for another one. In this way, detrimental effects of both industries to the environment can be reduced.[2,3] Therefore, cost, durability and environmental aspects are at a starting point of being used as important criteria in developing concrete technologies.[16]

When these by-products and solid waste residues are used as aggregate in concrete, they will gain a value as an alternative material to natural aggregates with a market

value. This waste-to-product approach creates new opportunities for industrial waste residues in several application fields.

Like in all new applications made with waste residues, chemical, physical and environmental effects may cause deterioration of the end-product resulting in damage to the product itself or to the structure. To investigate the concrete quality and durability, several tests and analytical methods are available. Concrete elements containing industrial by-products or solid wastes as aggregates replacement should be investigated carefully with regards to durability and mechanical properties.

In this work, the potential usage of Ferromolybdenum slag in concrete blocks for masonry work as aggregate's replacement is investigated. Production of a new type of concrete block, having similar properties to the concrete blocks made out of natural aggregates, is aimed for. A new field for FeMo slag utilisation is exploited.

Production of concrete blocks

Concrete commonly used to make concrete blocks is a mixture of cement, water, sand, and gravel. This produces a gray block with a fine surface texture and a high compressive strength. The apparent density of typical concrete blocks is about 1350 kg/m^3 for hollow blocks and 1750 kg/m^3 for the full ones. In general, the concrete mixture used for blocks has a higher percentage of sand and a lower percentage of gravel and water than the concrete mixtures used for general construction purposes. This produces a very dry, stiff mixture that holds its shape when it is removed from the block mould. In addition to the basic components, the concrete mixture used to make blocks may also contain various chemicals, called admixtures, to alter curing time, increase compressive strength, or improve workability. The production of concrete blocks consists of four basic processes: mixing, moulding, curing, and cubing. The following steps are commonly used to manufacture concrete blocks.

Batching and mixing

Sand, gravel and cement are transported to the concrete plant by truck. Certain materials, such as inert aggregates, are typically stored outdoors in stockpiles. Moisture sensitive materials, such as cement and fly-ash, may be stored in high-capacity silos. As the materials are needed, they are transported by conveyor to large storage bins at the top of the block plant. At the start of production, the raw materials are discharged into a weigh batcher, which measures the correct proportion of dry materials for the mix. The dry materials are mixed thoroughly before adding water and admixtures. The proportioning of the mix is carefully controlled by a computer. Most concrete blocks are produced using zero-slump concrete, which requires a minimal but very precise amount of water.

Moulding and curing

After mixing is complete, the batch is discharged into the hopper of the compacting machine. In a modern block making plant, blocks are produced on wooden or steel boards. The boards are empty when entering the compacting machine. First, the empty board is placed under the mould. Then, a filling box comes on the top of the mould and fills it from above taking care of an even distribution of the concrete. Next, the concrete is compacted in the mould by use of a tamper head and vibration. Finally, the mould is lifted, leaving the freshly formed block on the board. The filled board is then pushed out of the compacting machine onto a conveyor belt. As the block travels down the belt, a rotating brush removes loose particles of the aggregates from the top surface of the block. At this stage of the process, the uncured blocks are referred as "green" blocks. Afterwards these "green" blocks are placed into a curing chamber at normal temperature for at least 24 hours in order to harden and achieve the required mechanical properties.

Storage and transport

Boards of cured blocks are removed from the curing chamber and transported by the automated forklift to a stacking unit. Stacked blocks are then moved to an outdoor storage yard. Large quantities of blocks are stored until declared number is ready for transport to the construction site.

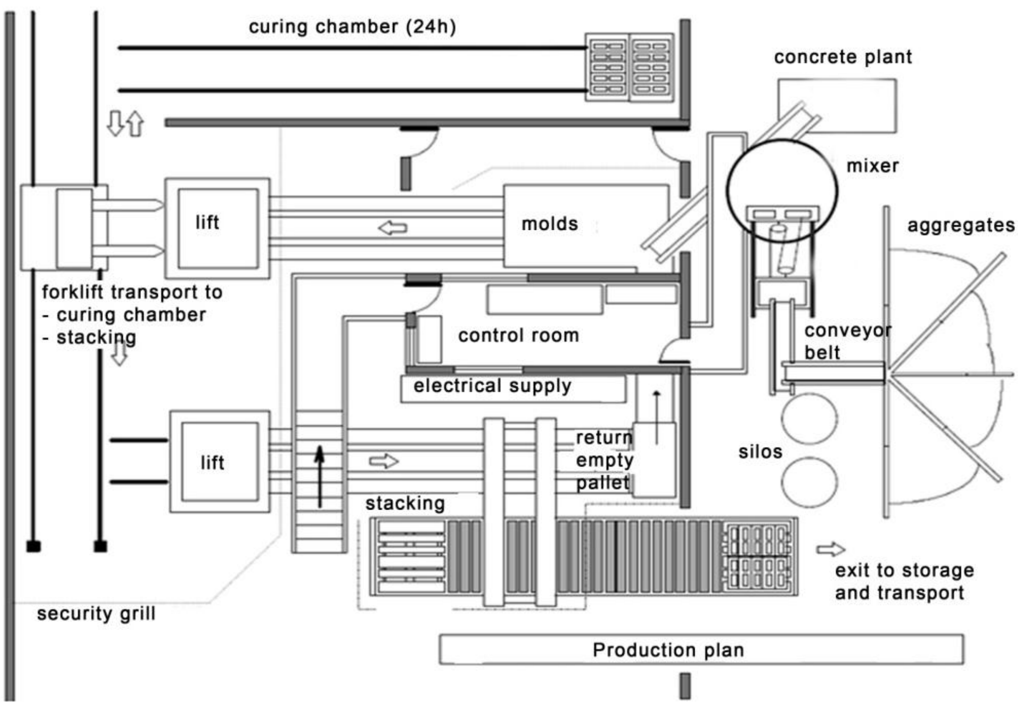

Figure 1: Production plant of concrete block making

Quality Control during production

The manufacture of concrete blocks requires constant monitoring to guarantee that the required properties are achieved. The raw materials are weighed electronically before they are placed in the mixer. The trapped water content in the sand and gravel may be measured with ultrasonic or microwave sensors, and the amount of water to be added to the mix is automatically adjusted to compensate. At the end of the mixing cycle, the exact moisture level is controlled in order to avoid a mixture being too wet or too dry. As the blocks emerge from the block machine, their height may be checked with laser beam sensors or other devices.

Materials

Classic raw materials

Although it is possible to produce concrete blocks with almost every type of cement, there are some factors to be taken into account:

- The blocks leave the curing chamber somewhere between 24 and 48 hours after production and have to be stacked in order to be stocked outside. At this moment, the blocks need to be strong enough to avoid damage during stacking. Therefore, rapid hardening cement with high early strength (CEM I-type cement) might be useful.
- When putting into place, the masonry block has to be resistant to certain chemicals (sulfates, chlorides, *etc.*) or to efflorescence by white deposits of water-soluble salts. One also has to consider the risk of damages caused by alkali-silica-reaction (ASR). Preventing ASR will provide a lasting stability of the block. The use of cement blended with blast furnace slag will reduce the risk of these damages. These considerations led to the use of CEM III – type cements.
- Sand that can be used for producing concrete blocks mainly comes from three sources, being sand from: (1) Riverbeds, such as the Rhine or the Meuse, having typically round grains (upstream sand contains little or no fines (maximum diameter up to 5 mm), while downstream sand becomes finer (1 mm or less)); (2) the sea (*i.e.* as fine as downstream river sand but rather angular); (3) quarries (as a by-product from the exploitation of limestone or sand found in the underground: these sands are rather fine and usually contain a lot of fines).

Usually, two types of sand are mixed. The influence on the workability of the fresh concrete mix, the influence on the final strength, and the texture of the block will determine the quantity of sand to be used in the mix. Probably excluding a number

of alternative production sites, aggregates used for concrete come from the same sources as sand does. The main difference is the particle size. The biggest sand grains are about 2 mm, which roughly equals the size of the smallest particle in aggregates. For the production of concrete blocks, aggregates up to 8 mm or sometimes 16 mm are considered. The most economical source of the materials used in block production is determined by its cost and the cost for transportation to the block making factory.

FerroMolybdenum slag (FeMo-slag) as partial replacement of aggregates[17]

Ferromolybdenum is an alloy of iron and molybdenum used primarily as an alternative additive in producing alloy steels, cast irons, and non-ferrous alloys. Ferromolybdenum slag is a waste-product formed in either the production of low carbon ferromolybdenum or high carbon ferromolybdenum. This waste is not expected to exhibit any hazardous characteristics. Under REACH, FeMo-slag is considered as "unknown or variable composition substance (UVC(B))", as shown in Table 1.[17]

Table 1: FeMo-slag composition

Unknown or Variable Composition Substance	Ferromolybdenum Slags
Synonyms/Trade Names	FeMo Slags
Formula:	By-product obtained during alumino-silicothermic reduction of roasted molybdenite concentrates (tech mo oxide) to produce Ferromolybdenum
TYPICAL COMPOSITION	
Parameter / Component	In % (mass)
Silicon	ca. 10 – 40
Aluminium	ca. 2 – 20
Iron	ca. 4 – 25
Molybdenum	ca. 0 – 2
Magnesium	ca. 0 – 5
Calcium	ca. 0 – 10

The annual production of FeMo-slag in Flanders is 20000 to 25000 tonnes. The granulated fraction which is used in concrete varies between 14330 and 19500 tonnes per year. In 2007 about 17000 tonnes of FeMo-slag was used in concrete products for road works, infrastructure, buildings and masonry concrete blocks. The environmental quality of FeMo-slags is given in Table 2. In view of the VLAREA-standards for metals, the enrichment of different metals is limited compared to

other waste streams of non-ferrous metals. However, in a VITO study[18] it is noticed that the concentration of Mo in FeMo-slag is increased (2088 - 4220 mg/kg TDS).

Table 2: Inventory of the amount of metals present in FeMo-slag (according to different public VITO-studies and certificates for use)

mg/kg TDS	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn
FeMo	4 - 15	0.1 - 0.3	41 - 799	180 - 357	< 0.2 - 0.5	49 - 118	29 - 129	105 - 504

Mix design

Composing the right mix for block production is a very complex balance between the visual result, the block quality and the cost of the raw materials. Some possible mixing formulas are given in Table 3.

Table 3: Mixing formulas for blocks (wt%)

Aggregates	Block for foundation masonry	FeMo-Block for foundation masonry	Block for industrial visual masonry
Sand 0/1 (quarry)	15%	15%	10%
Sand 0/2 (sea)	20%	15%	
Sand 0/2 (river)			30%
Stone 2/4 (quarry)			50%
Stone 4/6.3 (quarry)			
Stone 2/6,3 (quarry)	50%	25%	
Stone 6,3/14 (quarry)	15%		10%
FeMo slag		45%	
Cement CEM I 52,5 N	145 kg/m3		
Cement CEM III/A 42,5 N		180 kg/m³	
Cement CEM III/A 52,5 N			180 kg/m3

Concrete blocks made with FeMo-slag

Table 4 shows an example of the composition of R-blocks in comparison with that of normal produced blocks with virgin aggregates. In R-blocks about 45 wt% FeMo-slag is used instead of the fine and coarse aggregates in normal blocks. The starting point in designing the mix proportioning of the R-block is the fact that for economic reasons certain production parameters like workflow and production rate should preferably remain unaltered. Therefore, a similar granular gradation of the mixture with FeMo-slag was designed as shown in Figure 2.

Table 4: Mixing formulas for ordinary foundation masonry blocks (left) and foundation masonry R-blocks (with FeMo-slag) (right)

Mix Formula standard foundation block					
sieve passthrough [%]					
mesh [mm]	0/1 qr	0/2 sea	2/6,3 qr	6,3/14 qr	Standard
0.08	1.5	1.5	0.8	0.5	1.0
0.125	7.1	2.0	1.2	0.5	2.1
0.25	81.0	14.0	1.8	1.0	16.0
0.5	97.4	90.0	1.9	1.0	33.7
1	99.1	95.0	2.1	1.5	35.1
2	99.8	100.0	5.6	1.5	38.0
4	100.0	100.0	45.9	2.0	58.3
8	100.0	100.0	100.0	2.5	85.4
16	100.0	100.0	100.0	100.0	100.0

	0/1 qr	0/2 sea	2/6,3 qr	6,3/14 qr	Result
Mix [%]	15	20	50	15	100

Mix Formula R-block					
sieve passthrough [%]					
mesh [mm]	0/1 qr	0/2 sea	2/6,3 qr	FeMo	Result
0.08	1.5	1.5	0.8	2.2	1.6
0.125	7.1	2.0	1.2	3.5	3.2
0.25	81.0	14.0	1.8	6.0	17.4
0.5	97.4	90.0	1.9	8.0	32.2
1	99.1	95.0	2.1	13.0	35.5
2	99.8	100.0	5.6	20.0	40.4
4	100.0	100.0	45.9	37.0	58.1
8	100.0	100.0	100.0	76.0	89.2
16	100.0	100.0	100.0	100.0	100.0

	0/1 qr	0/2 sea	2/6,3 qr	FeMo	Result
Mix [%]	15	15	25	45	100

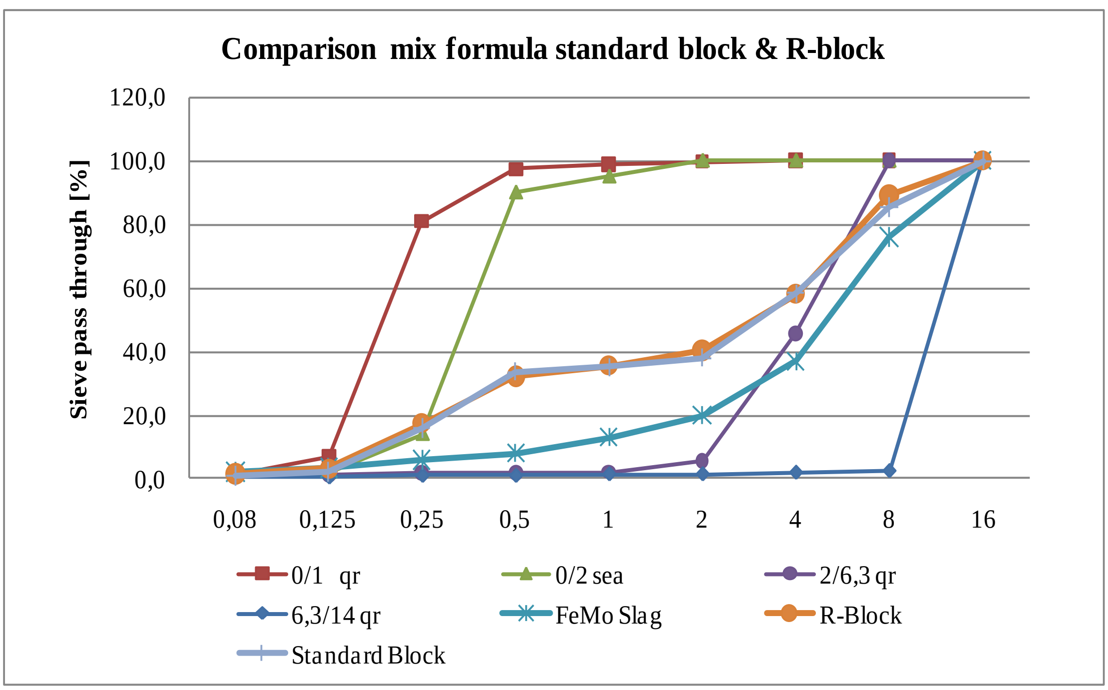

Figure 2: Comparison between the granular gradations of the mix proportioning for both types of blocks

Figure 3: An image of FeMo-slag aggregates

If one knows the optimal particle size distribution for the reference mix for a certain block using particular aggregates, then shifting to another aggregate can be easily done by calculating the new recipe by using the least square method to achieve the original optimal particle size distribution. This mix will have to be tested on the production machine, because small alterations in grain properties, such as rounded versus edged, will have an important influence on the distribution of the fresh concrete in the mould and might have a significant influence on the compacting of the block. These alterations may also have a visual effect as well as a change in the mechanical strength.

Having a good mixture composition is as important as having a good water/cement-ratio. This is not only important in terms of the mechanical properties of the blocks, but also important in terms of the production rate. Mixtures which are too dry can lead to slower production rates or even to stability problems of the freshly produced blocks causing them to fall apart. The concrete mixture has to be spread evenly in the mould. Therefore mixtures should not be too wet. All adaptations to the amount of water also lead to an adaptation of the cement needed. Although in theory, the mix formula can be calculated, it is the production machine and the test results of the block that will define the fine tuning of the mix.

Technical, mechanical and physical properties of the R-blocks

All blocks are BENOR certified and comply with the standards NBN EN 771-3+A1: Specification for masonry units - Part 3: Aggregate concrete masonry units (Dense and light-weight aggregates) 2005 and PTV 21-001: Technical Prescriptions: Masonry blocks in concrete 2006.

Table 5: Technical Properties R-Blocks

Technical Property	Description
Category of the block	Category I: blocks for load bearing masonry
Type of masonry (A = outside; B= visual; C = foundation; D= all other)	Type C (automatically complies for type D): blocks for foundation masonry (and other indoor masonry)
Size tolerance class	D1 (L, W, H : +3, -5 mm)
Shear strength	0,15 N/mm²
Reaction to fire	Euro class A1
Vapour permeability	µ = 5/15
Durability	complies
Toxic substances	none

Bringing the product to the market

When using an alternative raw material, such as slag, there are some important questions to be answered:

- Is it okay to use this alternative material? FeMo-slag is a waste product of an industrial process. By modifying the production cycle of the steel alloys where Ferromolybdenum is used and by treating the FeMo-slag, an alternative resource material for construction applications may be obtained. However, this product will have to meet several local regulations in order to be considered as a secondary raw material that can be used in concrete mixtures under specific conditions. These conditions will be noted in the certificate of use.
- What are the risks? The secondary material could have some chemical contaminations, which could interact with the cement in a negative way, or cause swelling problems leading to damage of the end-product, or cause visual damage like rusting.
- What is the perceptible influence of using secondary aggregates? Is the alternative material visible at the outside of the block or will it become visible when splitting the block?
- What is the influence on the weight? Ergonomics at the construction side and cost of transportation are important, but also issues like weight reduction without loss of strength or giving the block better insulation properties or make the block easier to cut and split. Even a block with more weight can find its way to the market when concrete is used as ballast as in river banks revetment or for soundproofing constructions.

Table 6: Mechanical and physical properties FeMo-Blocks

Production size (non- standard) [mm]	Quality-class	Compressive strength f_{bm} [MPa]	Density ρ [kg/m³]	Configuration EN 1996-1-1 Group 1: Full Block (voids ≤ 25%) Group 2 : Hollow Block (25%< voids≤60%)	Heat transmission $\lambda_{i,10}$ [W/mK]
288x138x190	15/2.2	≥ 15	2100	Group 1	1.30
388x088x190	12/2.2	≥ 12	2100	Group 1	1.30
388x138x190	15/2.2	≥ 15	2100	Group 1	1.30
388x188x190	15/2.2	≥ 15	2100	Group 1	1.30
388x088x190	10/2.2	≥ 10	1650	Group 1	0.91
388x138x190	6/1.4	≥ 6	1300	Group 2	0.88
388x188x190	6/1.4	≥ 6	1250	Group 2	0.88
388x288x190	10/1.4	≥ 10	1350	Group 2	0.88

When the first test results of blocks made with FeMo-slag were obtained, it was clear that this would lead to a solid block without perforations. Weight loss was almost undetectable. The use of FeMo-slag in the block was visible. FeMo-slag has colours like white, black, light green and light blue. In its appearance it resembles glass. Anyone who would work with these blocks would notice the strange granulates and start to ask questions. Therefore, before bringing this product to the market, more intensive testing had to be done and an open communication to the customers had to be made about the alternative aggregate used in the block, and proving its quality and safety.

More intensive testing was done in an external laboratory. This corroborated that the R-blocks complied with the Belgian Standard NBN B21-001. Furthermore, the first test production was kept in stock at the production site to see if the R-blocks had more efflorescence than standard blocks and also to see if any other negative effects, such as rusting, became visible. The FeMo-slags became slightly more noticeable after 4 to 6 months of aging. No other unwanted visible effects were detected.

When the concrete blocks made with FeMo-slag were first put on the market in 2003, they were sold under the name “Recy-block”, making clear to the customer that recycled aggregates other than natural aggregates were used. The customer’s

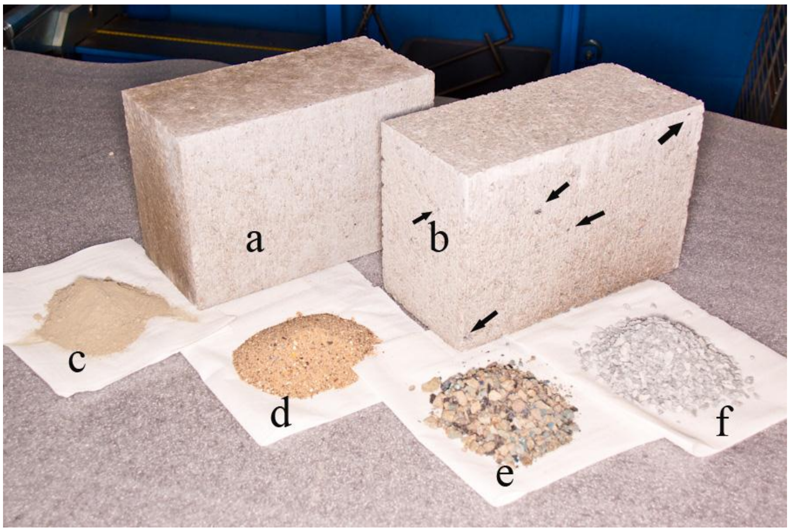

Figure 4: R-block and aggregates. The arrows indicate FeMo-slag visual at the surface of the R-block. (a) Standard block; (b) R-block with FeMo-slag; (c) Cement; (d) Sand; (e) FeMo-slag; (f) stone 2/6,3

interest in the Recy-block was raised by a sharp price policy of the new block. Clear and open communication to the customer about the use of FeMo-slag aggregates continued to be necessary.

Since the introduction of the CE-labelling on April 01, 2006, all concrete masonry blocks sold in the EEC have to comply with the new European Standard EN771-3. At first, it was decided to reach the level CE 2+, with external control. In doing so, the next step to follow procedures to obtain the Belgian "BENOR certificate" was not far off. The certificate that comes with CE, is issued by Probeton, the institute for standardisation of concrete products in Belgium. Probeton is also responsible for the BENOR-certificate. In Belgium, the BENOR-certificate is the ultimate argument in showing the costumer the good and constant quality of the product. At this stage, all tests that were needed for CE 2+ were done. With the former experience and the results of these tests, there was proof that the Recy-block, now called R-block, complied with all conditions needed to obtain a BENOR-certificate. For Probeton the general concern was not only the quality of the R-block, but also the stability of the quality in time and the safety for its users. After all, the BENOR-certificate is meant to give a lasting confidence in the product.

Steeplechase towards a BENOR-certified product

Chemical investigation

In cooperation with the producer of the FeMo-slag, a chemical and mineralogical study was performed. This proved that the FeMo-slag is stable and acts as inert

material. This study also gave an analysis of the chemical elements. For each element a lower and an upper limit was determined. Monthly reports provided by the producer of the FeMo-slag show that the chemical elements stay well between the limits. This way one can make sure that FeMo-slag always acts the same way in the end-product.

Physical investigation

As for any other raw material which is not certified by its producer, an incoming control has to be carried out. In this case, a sieve analysis in accordance with NBN EN 993-1 was established. A sample lot of the slag is taken every 2000 tonnes, and a sieve analysis report is kept at the production plant where the blocks are manufactured.

Influence of the slag on the hydraulic reaction of cement

It has to be proven that using the FeMo-slag instead of natural aggregates, does not have a negative influence on the hydration reactions of the cement, or on the mechanical properties of the block. Comparative tests between reference blocks without FeMo-slags and R-blocks containing FeMo-slags were made in which the compressive strength was controlled after 7, 14 and 28 days. The conclusion of this test program was that there was no negative influence on the hydration reactions of cement.

Durability

Concrete block are presumed to last for a long time. To prove the durability, the concrete blocks were submitted to classic tests such as resistance to frost and thaw. A very important risk with unknown aggregates is the possible alkali-silica reaction (ASR). Here intensive testing has also delivered proof that there is no risk for ASR.

Environmental safety

In order to evaluate the safe use of secondary aggregates in construction and road applications, VITO investigated the health impact of the use of secondary aggregates in replacing gravel during the production, construction and use phase.[18] In this study a policy decision supporting methodology was developed in which risks during the different stadia of construction or road applications were considered. In view of the composition of secondary aggregates in use today, the emphasis in this study is on the risks due to the presence of heavy metals. Four major waste streams form the origin of the secondary aggregates: non-ferrous metal slag (Pb, Cu and FeMo slag), steel slag (LD, stainless steel and furnace slag), bottom ashes (MSWI and CF bottom ashes) and recycled aggregates from construction and demolition waste. Currently, the annual production of recycled CDW aggregates is the largest waste stream

(9441000 t/y),[19] followed by steel slag (1900000 t/y), non-ferrous slag (325000 t/y) and bottom ashes (about 310000 t/y each).[20] Recycled CDW aggregates and all kind of slags can be used in concrete, while stainless steel slags find their use in asphalt road applications. LD slag and MSWI bottom ash are used in unbound road foundations.

In the VITO study[18] a classification of the metals in secondary aggregates according to the toxic damage to human life was made. As a result of this classification, Pb slags were classified as secondary aggregates with the highest priority to be investigated, followed by stainless steel slags, copper slags and MSWI ashes. Other secondary aggregates like FeMo slags, LDslags and recycled CDW aggregates, were classified as “no priority to investigate”. In the case of the production of concrete blocks with use of FeMo slag, test results of an investigation done by VITO made clear that the leaching of heavy metals was within the legal limits. Finally, all these elements were put in a dossier that convinced Probeton of the quality and the durability of the R-blok, produced with FeMo-slag. The Benor-certificate was obtained.

Conclusions

Ferromolybdenum slag can be successfully used in the production of concrete blocks substituting for natural aggregates. All properties meet the required values in order to certify these blocks according to BENOR. Blocks made of ferromolybdenum slag do not cause any hazard to human health or to the environment. However, obtaining a certification label for a product when using waste as an aggregate, is not straightforward. It is often difficult to meet the standards. One also has to overcome the prejudice that comes together with the connotation of “waste” in a waste-to-product approach. Therefore, to bypass this nuisance, it is better to indicate waste products as industrial by-products or residues, or in this case as secondary aggregates.

To bring the FeMo-block to the market a lot of measures had to be taken. The most important conclusion that can be drawn from this case is that besides having the blocks CE certified, which is mandatory, it is important to obtain the BENOR certification as well, in order to bring the product made with secondary aggregates to the Belgian market. Obtaining an “eco-label” is without doubt also beneficial in winning the consumers’ attention. The most important factor for both manufacturer and consumer is a competitive price for the product. Additionally an added value is created in using an industrial by-product as resource material in the production of a construction material.

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