Innovative hybrid fiber-reinforced shotcrete for thin repairing concrete overlays

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Abstract: Shotcrete is a technology patented in 1911 by Dr. Carl Akeley - curator at the Field Columbian Museum in, Chicago. The system enables one to place a cement-sand mix or concrete on various surfaces via high pressure and casing by means of special equipment - a shotcrete machine. In fact, this is a method for concrete casting by pressure through a hose and pipe-lines at high velocity into the surface. Two basic methods of shotcrete exist - "dry" and "wet" ones. The report discusses the main technological features of the two methods, analyzing their advantages and disadvantages. Emphasis is placed on the possibilities of rational choice of one of the two varieties of technology depending on multiple factors of complex nature. In a synthesized way are presented their potential for carrying out specialized construction works - repair, reconstruction and strengthening of damaged reinforced concrete constructions, consolidation of rock massifs and slopes, construction of tunnels, swimming pools and other special facilities. The effectiveness of the "wet" method is based to real possibilities to involve in concrete mix design different chemical innovative admixtures - ultra high range water reducing (HRWRA), shrinkage compensating (ShCA), internal crystallization one, etc. Preliminary estimates are presented for their economic expediency under specific conditions.
Keywords: *DRY AND WET SHOTCRETE, INDUSTRIAL CONCRETE STRUCTURAL REPAIR, FIBER-REINFORCED CONCRETE, HRWRA, INTERNAL CRISTALINE ADMIXTURES*

1. Introduction

The most industrial reinforced concrete structures usually suffer from different specific production and environmental aggressive factors. That means specific corrosion damages observed in time. Some of them needs urgent repairing actions.

Following good manufacturing practice, it means precise formulation of specific tasks, parameters and principal goal of repairing work, passing by developing of original structural design to increase the technical characteristics of the steel reinforced concrete structure to its initial (as designed) or better state. A basic requirement to the design is the observation of the principles of reasonable sufficiency of the offered solutions, concerning optimization of the thickness of the new concrete cover of the reinforcement, deposition of a low-weight anti-corrosion layer, protecting from atmospheric impacts, freezing, carbonation, UV rays, etc. In addition, development of technical regulations of the planned repair is also envisaged.

Nowadays some different types of ultra-thin concrete overlays are preferred for structural repairing. The usage of methods of shotcreting are enough reasonable. Shotcreting of a new special concrete mix design layer, without the use of formworks, employed to recover the initial cross section, seems to be the most appropriate technological method. Such an approach is adopted as a basic one in some technical projects, where as a technical-economical comparison between the two methods of shotcreting - "dry" and "wet" depositions, is presented below.

2. Shotcreting - basic principles, technological systems, technical comparisons

Shotcreting is a technology patented in 1911 by Dr. Carl Akeley. The system enables one to cast a cement-sand mix or concrete on various surfaces via high pressure by means of special equipment - a shotcreting machines. Two basic methods of shotcreting exist - "dry" and "wet" method [1].

A mix with cement and added sand (0-4 mm), prepared "dry" and deposited on a surface is known as dry shotcrete while that with aggregate fraction up to 20 mm - as sprayed concrete.

Regarding the "dry" method of casting (Fig. 1), a homogenized mix of cement and aggregates (usually with dimensions 4-20 cm, most often-up to 10 mm), with eventually added special liquid or/and dry powdered admixtures and various fibers, is prepared. It is carried to the hopper of the shotcrete machine (Fig. 2) and then conveyed under high pressure through a hose to a special mixing nozzle. Water is separately supplied through another hose.

The mix of homogenized dry materials and water is directly shot to the attacked surface, which can be horizontal, vertical or overhead (ceiling). There is not casing and no need of preparing a subsequent mix with conventional workability and compaction (with water/cement ratio significantly higher than that needed for matrix hydration).

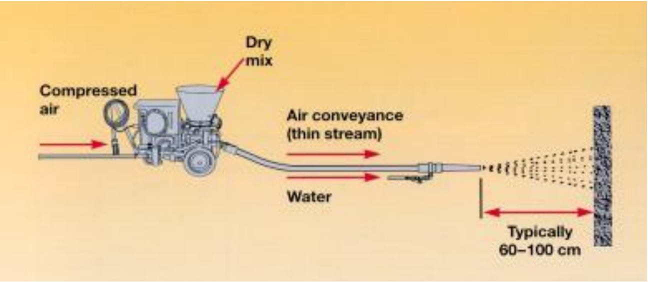

Fig. 1 *Dry shotcreting system*

Fig. 2 *Dry shotcrete machine*

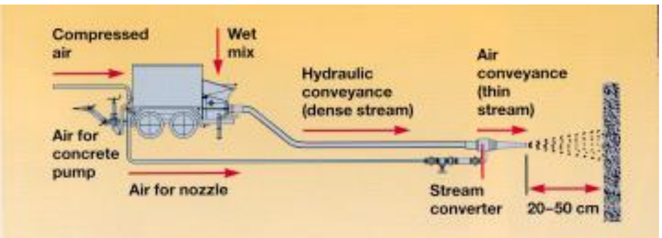

Fig. 3 *Wet shotcreting system*

Fig. 4 Wet *shotcrete machine*

Hence, the actual shotcreted mix is with significantly lower water/cement ratio (often in range of 0,35-0,40). This predetermines a number of essential concrete advantages- high density and strength, low permeability (high water impermeability), high corrosion resistance, minimized shrinkage etc.

The system for “wet” shotcreting (Fig. 3) employs special machines (**Fig. 4**) and supposes casting of a specific concrete mix. Its preparation is centralized in batching plant and its consistency is prescribed (the usual water/cement ration is below 0,45). The use of cement of good quality is desirable when applying both methods. Cement type can be CEM I 42,5 or CEM I 52,5R combined with appropriate cement replacing materials (fly-ash from thermal electric power stations, micro-silica powder, blast furnace slag), various powders or liquid chemical admixtures (bonding and hardening agents, internal crystallizations, shrinkage compensating admixtures, etc.), efficient fiber-reinforcement (steel and/or polymer fibers).

The limits of optimal aggregate sieve curves is shown in Fig. 5 in accordance of requirements of **European Federation of National Associations Representing producers and appliers of special building products for Concrete, EFNARC European Specification for Sprayed Concrete** [2]. It is seen that the dry method supposes the use of finer fractions of aggregates.

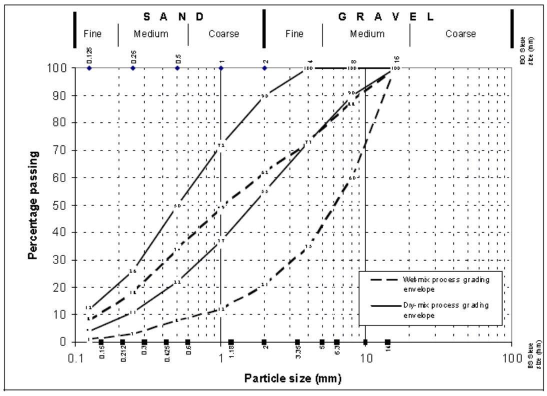

Fig. 5 *Optimal limits of aggregates sieve curves to “dry” and “wet” shotcrete*

Mix fibers are bound to oppose the formation of micro-cracks due to shrinkage and other genesis, and they increase the abrasion and shock resistance, tension and bending strength, as well as ductility. When using structural steel or polymer fibers, the fiber length should not exceed 70% of the internal diameter of the used pipes or hoses, except for the case when preliminary tests prove that longer fibers can be shotcreted without blockage.

Prior to mix casting, one should appropriately prepare the surface- remove surface non-bonded unsound particles, perform qualitative water saturation, assemble the reinforcing mesh if planned, mark the designed thickness and stop eventual leaks.

Mix casting proceeds in layers with different thickness of an order 3-8 (12-15) cm depending of the casting conditions – surface type (outdoor or underground rock massive, old concrete, brickwork, earth embankment, repair etc.), site characteristics, operator’s skills and admissible rebound of the material impelled onto the surface (i.e. shotcreted concrete that should stuck to the surface). Each layer is successively deposited after the previous one has attained a specific strength.

Usually, the surface should be manually finished after attaining the designed layer thickness using wooden or magnesium mortar boards. Then, concrete should be looked after pursuant to the good manufacture practice.

The designed characteristics of concrete are proved by a special sampling (preparation of so-called concrete “panels” during concrete casting and subsequent core drilling) and by core testing in conformity with the actual standards.

A comparison between the basic advantages and disadvantages of both methods of shotcreting based on their potential to guarantee layer’s specific technical and other properties is given in Table 1. The comparisons are made taking into account specific building project (Silos for Light Soda, SOLVAY SODI JSC, town of Devnya, Bulgaria - Photo 1**),** where the first designer's proposal is based on "dry" shotcreting by using a ready-made product **MC Torkret W-81.**

Photo 1 *- Silos for Light Soda, SOLVAY town of Devnya, Bulgaria*

Generally, the choice of a method of shotcreting should be based on a multifactor analysis accounting for a maximal number of technical-technological and economic factors (sometimes contradicting each other). So called **theory of five “W”-questions (What? Why? Where? When? Who?)** is especially popular in specialized literature [3]:

What – defines the type and goal of work;
Why – whether one has correctly selected the shotcrete technology from a technical-economical point of view, which technology is “Yes”;
Where – site, peculiarities of object location and possibility to arrange the equipment and supply materials;
When – climate in the course of operation, exploitation terms and start;
Who – who is the contractor; are all technical and personal requirements to the execution of task available?

Trends of possible comparisons between the two shotcreting methods are numerous but they can be synthesized as follows:

“Dry” shotcreting, especially based on operations with representative materials, previously selected and packed, is a simplified technology. It is effective under tough conditions - hardly accessible mountain sites, small areas bound to single stage deposition, small coating thickness, limited productivity and prolonged terms of deposition. The inevitable subjectivity of the choice of deposition is a peculiar disadvantage of the method (the basic technical characteristics of the ready product depend on the subjective water dosage by the nozzle-man operator). The intensive dusting during operation is also a major disadvantage.

„Wet” shotcreting is based on work with certified concrete mixes, being “intentionally” designed and industrially prepared. Their optimization is flexible to meet the specific technical requirements and conditions of exploitation. A potential of multi-factor optimization of the concrete mix design also exists. It consists in the variability of selection of cement, aggregates, special chemical admixture with strong water reduction effect, special in-depth crystallizers and polymer modifiers, shrinkage compensating agents, fiber-reinforcement consisting of various types of fibers, etc. The basic advantages of the method are its increased productivity, possibilities of a single-stage deposition of a thick layer, minimal operational subjectivity and increased ecology-friendliness of mix homogenization and casting. A disadvantage of the method is the impossibility of its application if there is no certified concrete plant nearby.

Table 1 *COMPARATIVE TABLE to characterize the peculiarities of "wet" and "dry" shotcreting*

Index	**Wet shotcrete - GENEGAL (variant proposed)**	**Dry shotcrete - GENEGAL (MC Torcret W-81)**
Cement type	Due to production requirements (sulfate resistant)	Due to production requirements (sulfate resistant)
Max size of aggregates (D_{max}), mm	Up to 25 (8)	to 8 (5)
Minimal single layer maximal thickness, mm	In function of (D_{max}) (30)	20 (25)
Maximal single layer thickness, mm	Up to 200 (200)	Up to 30 (30)
Maximum total laying thickness, mm	Up to 400 (400)	Up to 100 (100)
Possibility for fiber-reinforcing with: - shrinkage-compensation function; - structural function	Yes (yes) Yes (yes)	Yes (no) No (no)
Compressive strength at 28-days of age, MPa	30-60 (60)	30-80 (45)
Rebound (vertical casting) in total thickness of 100 mm,%	10-20 (10-15)	20-40 (15-25)
Adhesion to prepared old concrete surface, MPa	1-2 (1,5)	1-2 (1,5)
Water absorption, %	(8)	(9,4)
Frost-resistance class C_{fr} (BDS EN 206:2014+A1:2016/NA: 2017 – NA.0.2)	(200)	(200)
Possibility to use super-plasticizers (poly-carboxilates)	Yes (yes)	No (no)
Possibilities to incorporate in concrete mix special deep crystallization admixtures – self-healing, water-proof concrete, 4G - impermeable concrete	yes (yes)	yes (no)
Time depending concrete pore structure with positive effect to impermeability of the cross-section	Yes, permanent deep crystallization with self-healing action	No permanent deep crystallization with self-healing action
Water impermeability (BDS EN 206:2014+A1:2016/NA: 2017)	Вв1,0	(no data available)
Depthofpenetrationofwaterunder pressure (BDS EN 206:2014+A1:2016/NA: 2017)	up to 10 mm	no data available
Possibility for concrete polymer-modifying	Yes (Yes)	Yes (Yes)
Active dusting in operation	No (No)	Yes (Yes)
Disadvantages due to max layer thickness – Disadvantages due to max layer thickness – lenses (delaminating potential)	 None	 Yes

Preliminary economic considerations prove the advantage of "wet" shorcreting over "dry" shotcreting (regarding identical technical characteristics, enough water volume and a possibility to shorten the term of deposition).Yet, for the sake of correctness, each comparison requires precise specification of all conditions of mix deposition.

3. Analysis of the adopted technical method of repair of HEAVY SODA SILOS - advantages and disadvantages

A repair and recovery of the steel reinforced surface of **HEAVY SODA SILOS** (the job site is near to the **LIGHT SODA SILOS)** are partially underway at the moment. The technological order of work includes treatment of the entire uncovered surface by sand blasting, mechanical treatment of visibly "weakened" areas in-depth of the cross section, cleaning and dust removal, anchoring of an additional steel welded mesh N8 (15x15 cm), corrosion protection of the uncovered reinforcement and the new mesh, "dry" deposition of three layers of representative dry shotcrete, type **MC Torkret W81,** with total thickness of 7-8 cm, deposition of a moisture blocking membrane based on **Colusal MK** and polymer (secondary) finish protection **MC DUR 2496 CTR -** all prepared and supplied by **MC Bauchemie, Germany**.

The technical characteristics of the used "dry" shotcrete mix are given in two technical sheets- Bulgarian translation and an original English text. Note however the essential difference between the two documents regarding the specified actual parameters - Table 2.

The analysis of data submitted in the Bulgarian text shows non-proportionately high frost resistance of 200 cycles at a significant value of water absorption of 9,4% - we believe that the lack of such data in the English text is not accidental.

There is an essential mismatch between the declared values of the degree of adhesion to the substrate- it is over 3,00 MPa in the Bulgarian version while it exceeds 1,5 MPa in the English text.

Table 2 *Technical characteristics of "dry" shotcrete MC Torkret W81*

Characteristics	**Value in:**	
	Technical data sheet in Bulgarian	**Technical data sheet in English**
Maximal size of aggregate particles, mm	5	8
Compressive strength at age of: - 7 days, MPa - 28 days, MPa	 37 over 40	 over 35 over 45
Adhesion to the substrate, MPa	over 3,00	over 1,50
Water absorption, %	9,4	-
Frost resistance, cycles	200	-
Rebound, %, from a vertical surface and at layer thickness: - 25-30 mm - 30-100 mm	 - -	 25-35 15-25

Yet, the English text provides plausible data, too (confirmed by other references) concerning rebound during shotcreting of a vertical surface and different values of layer thickness. The latter amounts to 25-35% of a thickness ranging from 25 to 30 mm (the thickness of a monolayer of shotcreted heavy soda silos), and to15-25% of a thickness ranging from 30 to 100 mm. Such data lack in the Bulgarian version.

Both documents do not specify concrete type and class. Yet, appliers claim that the dry mix for shotcreting of heavy soda silos is based on sulfate resistant cement, which is the requirement of SOLVAY SODI JSC. The above arguments justify the use of the English data in further comparisons.

We will discuss below the difference between the total cost of the offered technical solution and that of the actually executed repair of heavy soda silos after a precise description of the entire technological system for "wet" shotcreting.

4. Proposed new technical solution using the method of "wet" shotcreting

Repairing works of concrete and steel reinforced concrete structures of different type via shotcreting is a comparatively obscure activity in Bulgaria. Most often, the available experience is reduced to shotcreting aiming at:

- consolidation of earth/rock massifs in infrastructural (tunnel in particular) and hydro-constructions;
- repair-recovery – tunnel facing, piers and posts of bridge structures, towers and chimneys etc.;
- increase (rarely) of the bearing capacity of existing steel reinforced structures – in cases when the bearing capacity is not proved (in new constructions) or as a structural necessity if the exploitation conditions change.

In our case, besides the existing knowledge, the confidence in applying a system for repair and recovery of steel reinforced structures of light soda silos via "wet" shotcreting is also based on a project which was successfully executed recently. The technology is based on the specific technical characteristics of a specially designed concrete mix.

Photo 2 *Part of the technological equipment*

Photo 3 *Supporting wall prepared for shotcreting*

Photo 5 *Shotcreting process*

Photo 7 *"Wet" shotcreted wall*

We performed a complex structural study of the steel reinforced structure of a hotel in the tourist resort "Albena" newly erected at the beginning of the present year. We unambiguously found that concrete of the foundation, especially at the low levels of the bearing steel reinforced concrete structure, does not meet the requirements of the designed class of strength. Hence, strengthening of the cross section of the bearing steel reinforced elements (columns and supporting walls) was recommended. This was to be done by installing an additional steel reinforcement and increase of the cross sectional area by shorcreting a 10-cm thick layer of special highly- technological and fine-grain mix for "wet" shotcreting. It was to provide a compressive strength of C30/37 and high technological degree, as well as a possibility of single shotcreting of a layer with thickness larger than 10 cm at minimal rebound and productivity of 30 m^3 daily.

The task was successfully executed where the reinforcement was performed within 5 days and the shotcreted area exceeded 200 m^2 - **Photos 2-5**.

Despite the offered design or the higher exploitation capability claimed, the specificity of the present project requires that the repair guarantee a specific degree of structure durability under specific corrosion attack on concrete and steel reinforcement. It is based on the specification of the minimal requirements to the concrete substrate and reinforcement cover, pursuant to **BDS EN 1992-1-1:2005 Eurocode 2: Design of concrete steel reinforced structures, Part 1-1: General regulations and regulations for buildings, National appendix (NA:2011),** respectively**.**

In addition to the mechanical impacts during exploitation, the structure simultaneously undergoes a durable influence of environmental and exploitation factors – i.e. physical and chemical impacts. The latter are classified in **BDS EN 206:2013+A1:2016 Concrete. Specification, properties, preparation and correspondence,** resp. **National Annex / NA:2017.**

It may generally concludes that the silo steel reinforced concrete structure operates under combined impacts of several aggressive factors - **Table 3.**

Table 3 *Generalized specification of the aggressive site-factors due to exploitation and surrounding medium*

Class specification	**Medium description**
Corrosion due to carbonation XC4*)	Cyclic wetting and drying
Corrosion due to non-sea water chlorides XD1	Moderate humidity
Corrosion due to sea water chlorides XS1	Impacts of air salts without a contact with sea water
Impacts due to freezing/thawing with or without thawing agents XF1	Moderate water saturation in the absence of a thawing agent
Chemical attack XA3**)	Environment yielding strong chemical aggression

Note:
***)** Intense carbonation due to technological factors and operated by CO_2.
****)** Intense complex chemical attack of different character, for instance attack of nitrogen oxides and chlorine compounds in the air

Following the respective standard requirements (**BDS EN 206:2013+A1:2016 Concrete. Specification, properties, preparation and correspondence, National Annex/NA:2017, Table F1)** some specific (limited) concrete characteristics are given below:

- **Compressive strength class C35/45;**
- **Maximal water/cement ratio 0,45;**
- **Minimal cement contents 360 kg/m^3;**
- **Sulfate resistant cement.**

Pursuant to **BDS EN 1990:2003 (Eurocode 2): Basic of structural design, Item 23 (Designed exploitation term), Table 2.1,** silos should be specified as installations with a post-repair exploitation term of **"category 4" (corresponding to exploitation term of 50 years).** Consider herein that the basic bearing reinforcement after repair-recovery is not violated- it is cleaned from corrosion damage, recovered after break, reliably protected by deposition of a new anti-corrosion coating. Besides, a steel welded mesh is additionally fixed to the main reinforcement thus processed.

In our case, the below procedure concerns the specification of the thickness of the concrete cover of the external face of the additional mesh. This in fact provides additional resource of the newly deposited cover.

Concrete cover is the distance from the surface of the outer reinforcement (including joints, stirrups and surface reinforcement) to the closest concrete surface. The nominal concrete cover **(C_{nom})** is found as a sum of the minimal cover **(C_{min})** plus addition **(ΔC_{dev}):**

$$C_{nom} = C_{min} + \Delta C_{dev}$$

The minimal concrete cover (**C_{min}**) should transfer cohesion forces, provide steel protection against corrosion (durability) and fire resistance. The adoption of the maximal value is mandatory:

$$C_{min}=\max\{C_{min,b};\ (C_{min,dur}+\Delta C_{dur,\lambda}-\Delta C_{dur,st}-\Delta C_{dur,add});10mm\}$$

$C_{min,b}$ - minimal cover providing cohesion (see **Table 4.2.** of **BDS EN 1992-1-1:2005 –** considering individual non-stressed bars, it is equal to bar diameter, 28 mm in this case);

$C_{min,dur}$ - minimal cover protecting against environmental impacts (see **4.4.1.2. Item 5**. of **BDS EN 1992-1-1:2005 –** considering structures, class S4, with individual non-stressed bars, corrosion class XD1, it is equal to 35 mm);

$\Delta C_{dur,\lambda}$ - safety addition (see **4.4.1.2. Item 6.** of **BDS EN 1992-1-1:2005/NA –** equal to 0 mm);

$\Delta C_{dur,st}$ - decrease of concrete cover when using stainless steel, **equal to 0 mm**;

$\Delta C_{dur,add}$ - decrease of concrete cover by applying additional protection, no protection here, equal to 0 mm.

Hence, the minimal necessary thickness of concrete cover is**:**

$$C_{min} = \max\{28;\ 35;\ 10\ mm\} = \underline{35\ mm}$$

5. *Mix design of polymer-modified, hybrid fiber-reinforced fine-grain concrete with included internal-crystallization admixture used for "wet" shotcreting*

Concrete mix design developed herein correspond to the offered technological system of repair and recovery of individual sections of the structure.

Table 4 *PRESCRIBED MIX 1 (WS)*
of HYBRID FIBR-REINFORCED POLYMER-MODIFIED FINE-GRAIN CONCRETE (D_{max}= 8 mm) for WET SHOTCRETING
with compressive strength class C35/45 and resistant to environmental aggressive agents: XC4, XA3, XF4, XD1, XS1

INGREDIENTS	**QUANTITY, kg/m^3**
Sulfate resistant portland cement CEM I 42,5 SR5, DEVNYA	550
River sand, SILISTRA, "POLARIS - 8", fraction 0-4 mm	745
Crashed washed sand, ESKANA, "Sini vir ", fraction 0-4 mm	300
Crashed stone, PATSTROY,town of Karnobat, fraction 4-8 mm	505
HRWRADYNAMON SX, MAPEI, Italy– 0,6% of cement mass	3,30
PP-fibers FM150, Propex Concrete Systems, USA	0,900
PP- fibers FM300, Propex Concrete Systems, USA	0,900
KMC – thixotropic polymer modifier increasing mix compactness (water solution of 10% dry compound – conforming to a prescription)	10,00
Internal-crystallization chemical admixture KRYSTALINE ADD+, Spain	6,0
Mixing water (for dry aggregates)	~190
Consistency (regarding to slump test), cm	S1

The included special chemical admixtures aim at the improvement of the internal-structural characteristics of the mix and hardened concrete. The high range water reducing admixtures (HRWRA) **DYNAMON SX** based on acrylic polymers provides low water/cement ration at an optimal deposition consistency of the concrete mix. The internal-crystallization chemical admixture **KRYSTALINE ADD++** provides high degree of concrete water impermeability (steadily increasing in time) based on additional chemical reactions running in hardened concrete in contact with air moisture. The combined fiber-reinforcement consisting of two types of micro-polypropylene fibers FM150 and FM300**,** not only improves all parameters of the concrete mix during a pre-structural state (homogeneity, segregation, lack of de-lamination and water release from the surface) but also increases concrete impermeability, frost resistance and the surface hardness of hardened concrete, reducing rebound during shotcreting.

Thus, extremely high quality of **one-layered** concrete deposited by means of wet shotcreting is attained. This is done employing a combined technically useful and profitable technology. The layer thickness is approximately 8-9-cm, it saves concrete passivity to additional reinforcement, having maximal degree of resistance to specific aggression of the exploitation and surrounding medium.

A special repair/recovery **MIX1 (WS)** is designed for "wet" shotcreting of an outer cylindrical shell and load-bearing steel reinforced columns with outer exposed walls. The mix consists of polymer-modified hybrid fiber-reinforced concrete (maximal size of coarse aggregate D_{max}= 8 mm) and internal-crystallizing chemical admixture - Table 4.

The aggregates sieve curve of the designed mix (the blue line) is optimally close to the theoretical one (the violet line) pursuant to the requirements of **DIN 1045 -2, 2008-08: Tragwerkeaus Beton, Stahlbeton und Spannbeton1, Teil 2: Beton - Festlegung, Eigenschaften, Herstellung und Konformität - Anwendungsregeln zu DIN EN 206-1**, which supposes the highest mix compactness - Fig. 6.

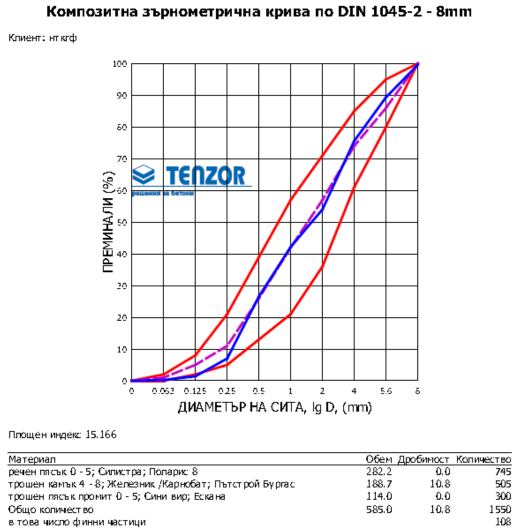

Fig. 6 *Aggregates sieve curve of the offered concrete mix for "wet" shotcreting*

6. *Cost analysis (VAT excluded)*

Regarding the declared density of the dry mix **MC Torkret W 81 (MC)** of about 2020 kg/m^3 and the regular material cost amounting to **0**,55 BGN/kg, the cost of the dry shotcreting mix turns to be about 1111,00 BGN/m^3. Accounting also for the declared material rebound of about 30%, the cost of dry shotcreting mix rises to about 1450 BGN/m^3.The latter significantly exceeds that of the main and special materials used for the preparation of 1 m^{3}mix for "wet" shotcreting.

Besides, the adopted technical solution includes secondary corrosion protection via deposition of a special polyurethane composition **MC DUR-2496 CTR**, where material cost, only, is about 45 BGN/kg. At a consumption rate of about 0,200 kg/m^2, the cost of deposition rises to 9,00лв./m^2. Adding costs of priming mix and labor yields a total cost of about 20-25 BGN/m^2.

The offered technological system of repair of silos for heavy soda via "wet" shotcreting is based on the use of highly technological, polymer-modified, hybrid fiber-reinforced fine-grain concrete (with maximal size of the large aggregate D_{max}= 8 mm) and internal-crystallization chemical admixture. The mix is resistant to specific impacts of the exploitation and surrounding media. Thus, the necessity of design and deposition of a secondary polymer protection falls off.

The cost of 1 m^3 of **MIX 1 (WS)** prepared in a batching plant, including all main and special materials, approximately amounts to 350 $BGNm^3$.

An approximate objective comparison between costs of the main materials (the designed ones and those used in the actual repair) is given in Table 5.

Table 5 *Comparison of the approximate costs of both repair systems*

MATERIALS	**Technological system, BGN/m^2**	
	MC Torkret W 81	**Mix 1 (WS)**
Material cost of a deposited cover, (BGN/m^2) per thickness (cm)	94,25 (for 6-7cm)	31,50 (for 9 cm)
Cost of the necessary secondary polymer protection - materials and labor	20,00	0,00
TOTAL:	**114,25**	**31,50**

The price comparisons performed show a significant advantage of using the proposed Mix 1 (WS) for "wet" shotcreting. The declared design characteristics of the same gave SOLVAY SODI JSC the task of conducting parallel tests in real production conditions for establishing the basic physic-mechanical and special technical characteristics of the two competitive concrete through specialized sampling and standard testing in laboratory conditions - the one for dry spraying **MC Torkret W-81** and the proposed new **Mix 1 (WS)** for "wet" spraying - Photos 8, 9, 10, 11.

Photo 8 MC *Torkret W81 spraying*

Photo 9 "*Wet" WS spraying*

7. Conclusions

The analysis of the experimentally found physic-mechanical and structural characteristics of the analyzed mixes for shotcreting is already published [4] and gave us to make the following conclusions:

The physic-mechanical and structural characteristics of the proposed repair-recovery **Mix 1 (WS)** for "wet" shotcreting significantly surpass those of mixes used in the repair of silos for heavy soda and prepared by MC BAUCHEMIE **MC Torkret W-81.**

The **Mix 1 (WS)** for "wet" shotcreting displays strength-deformation and structural characteristics typical for performance shotcrete of the newest generation - high strength, elasticity modulus and degree of frost resistance. The mix properties combined with its high impermeability to aggressive agents (inclined to increase during exploitation) makes it entirely applicable from a technical-economical point of view in the repair-recovery of light soda silos "4" and "5".

Summarizing all above mention considerations SOLVAY SODI JSC made a fully informed choice to outsource the repair of light soda silos using the newly developed **Mix 1 (WS)** high-tech composition. Currently, the design procedures are finished and construction works are ready to start.

Acknowledgments

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References

1. D. Bittner, Shotcrete: Wet process versus dry process, *Concrete Repair Bulletin, July/August, 2015, www.ICRI.org.*
2. European Specification for Sprayed Concrete, *EFNARC, Association House, 99 West Street, Farnham, Surrey, GU9 7EN, U.K - ISBN 0 9522483-1-X,1996.*
3. J. Bertrand, Shotcrete Supply: Dry or Wet? A Shotcrete Supplier's Perspective, *Shotcrete, Spring, 2006.*
4. V. Naidenov, An innovative approach for repairing of corroded reinforced concrete industrial structures in aggressive environment by high-tech hybrid reinforced sprayed concrete with capillary crystalline admixture, *MACHINES, TECHNOLOGIRS, MATERAILS (MTM), Year XIII, ISSUE 6/2019, ISSN PRINT 1313-0226, (259-262).*