Bonding ability of slags

Research on the management of waste, materials and other products of metallurgy and related sectors

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Production of slags from pig iron and steel manufacturing

	Metal production	Slag production	Specific production
	(kt)		(kg_{slag}/t_{iron}) (kg_{slag}/t_{steel})
Pig iron manufacturing	4 039	1 529	379
Steel manufacturing	4 974	658	Total 132 - furnace 115 - ladle 22

Data for the year 2013, ArcelorMittal Ostrava a.s. TŘINECKÉ ŽELEZÁRNY, a.s. VÍTKOVICE STEEL, a.s VÍTKOVICE HEAVY MACHINERY a.s.

Bonding ability of substances

Binders	
Substances connecting particles of other solid matter together	
Hydraulic binders	**Latent hydraulic binders**
• There are created products, which firstly harden in the air, later harden and become solid both , in the air and water as well	• Hydraulicity manifests in effect of activator ($Ca(OH)_2$, water glass), water itself is insufficient for initiation of reactions
• Hydraulic phases β-C_2S, C_3S, C_3A, $C_{12}A_7$, C_2F, C_4AF, less important is content of C_3MS_2 • (C – CaO, S – SiO_2, A – Al_2O_3, F – Fe_2O_3, M – MgO, and C_2S is $2CaO{\cdot}SiO_2$)	• Al_2O_3 and SiO_2 have to be included in amorphous state, CaO helps to form hydraulic products
Slags can show both, hydraulic and latent hydraulic ability as well	

Requirements on slags

Common hydraulicity	Latent hydraulicity
Presence of hydratable phases β-C_2S, C_3S, C_3A - determined by the presence of enough big amount of CaO	Sufficient amount of glassy phase - fast cooling down - related to → composition → viscosity curve → transition temperature
- slow cooling transformation β-C_2S → γ-C_2S ≈ **10 %** volume change → disintegration of slags - hydration of free CaO and MgO → disintegration of slags	Blast furnace slag contains ca. 40 wt.% SiO_2 → guaranteed vitrification
Better suits **steel** slag	**Granulated blast furnace slag** (standard industrial product) suits to all requirements

Typical slag composition

Slag	Composition (wt.%)				
	CaO	SiO_2	Al_2O_3	MgO	$FeO+Fe_2O_3$
Blast furnace	35-38	[illegible]4-38	6-9	10-14	0,5-1
EAF	35-60	9-20	2-9	5-15	15-30
BOF	30-55	8-20	1-6	5-15	10-35
Ladle	**30-60**	**2-35**	**5-35**	**1-10**	**0,1-15**

C:S≈1:1

C:S>1

Theoretical and real phase composition of ladle slags

Precondition $\Sigma(CaO, SiO_2, Al_2O_3)=100\%$

X-Ray phase diffraction

The region of lower SiO_2 content

Balanced phase association

- C_2S – C_3A - C_3S
- C – C_3S – C_3A

γ-C_2S , β-C_2S, $C_{12}A_7$, merwinite C_3MS_2, gehlenite C_2AS, anortite CAS_2, C_3S, Ca_2AlMnO_5, CaO, Ca_2AlMnO_5

The region of higher SiO_2 content

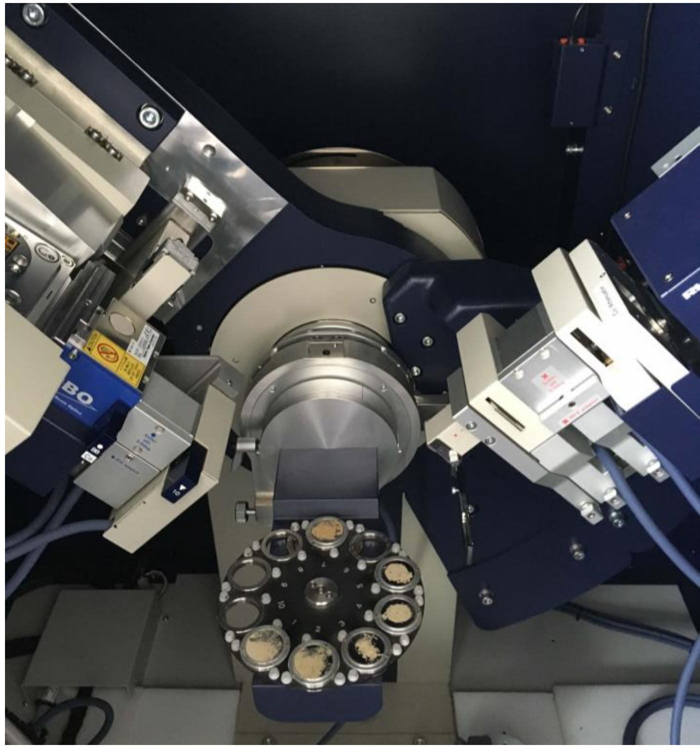
Balanced phase association

- C_2S – C_3A – $C_{12}A_7$
- C_2S – C_2AS – CA
- C_2S – C_3S – C_3A

γ-C_2S, α'-C_2S, $C_{12}A_7$, akermanite C_2MS_2, gehlenite C_2AS, anortite CAS_2, MgO, MgO.FeO

Real phase composition of slags

- BF slag
  - Aggregate – gehlenite, akermanite
  - Granulated – glassy phase
- Steel furnace slag
  - β-C_2S, FeO, brownmillerite, CaO
- Steel ladle slag
  - β-C_2S, γ-C_2S, C_3S, MgO, merwinite, gehlenite, akermanite, brownmillerite



β-C_2S, C_3S are hydraulic phases → possibility to use slags bonding ability

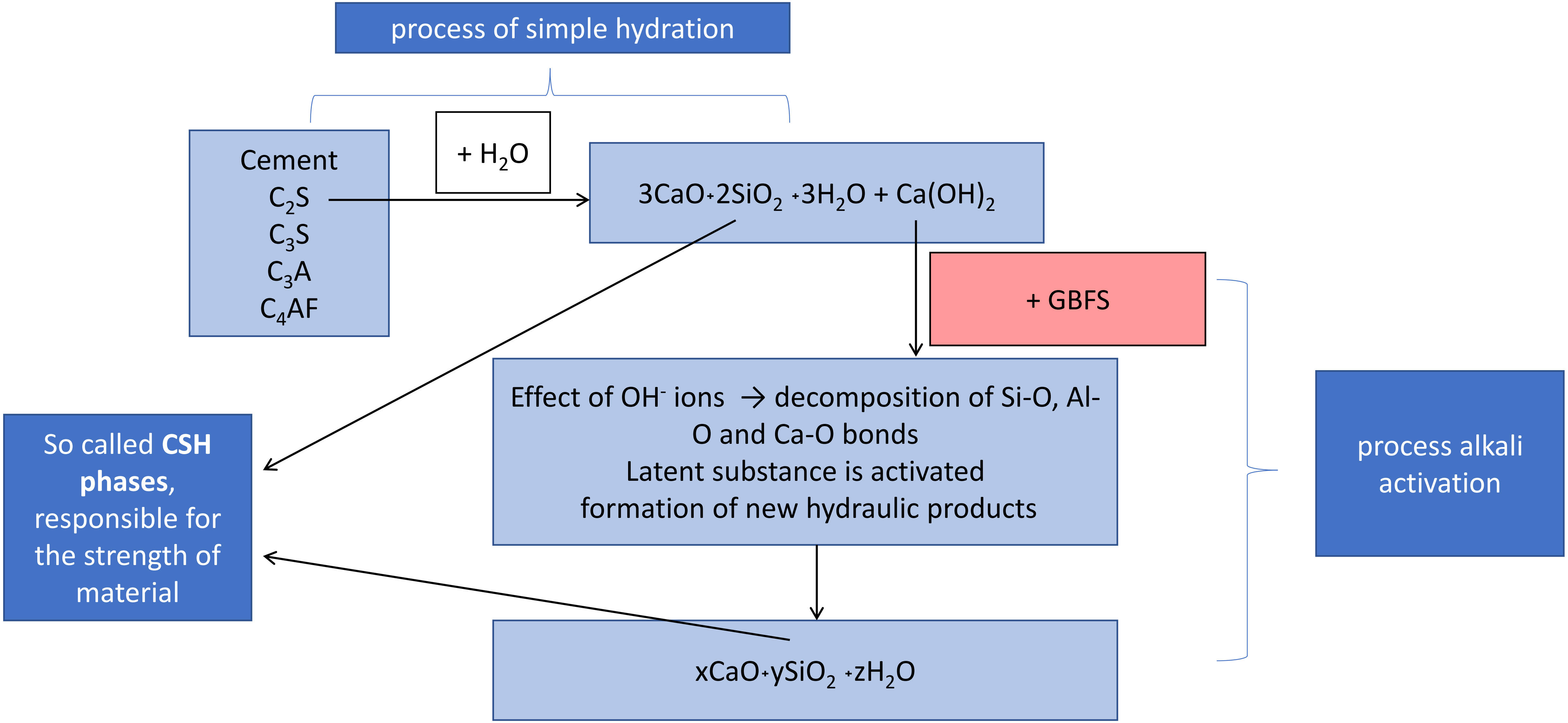
Standard use of granulated BFS

Cement class	Cement name	Cement mark	Clinker	GBFS	Other main additional components
			(wt.%)		
II	Slag	II/A-S	80 – 94	6 – 20	-
		II/B-S	65 - 79	21 – 35	-
	Portland blended	II/A-M	80 - 94		6 – 20
		II/B-B	65 - 79		21 – 35
III	Blast furnace	III/A	35 – 64	36 – 65	
		III/B	20 – 34	66 – 80	-
		III/C	5 - 19	81 -95	-
V	Blended	V/A	40 – 64	18 – 30	18-30
		V/B	20 – 38	31 - 50	31-50

Up to 95 %

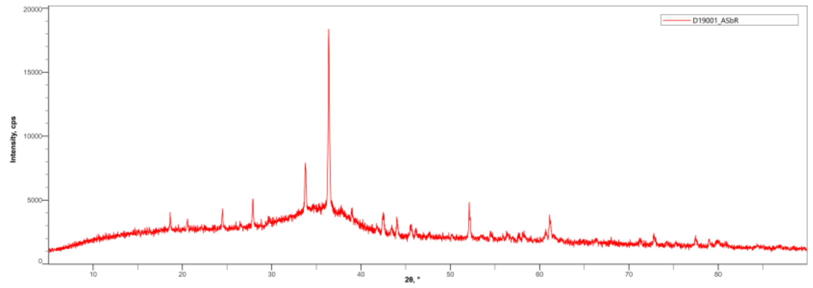
ČSN EN 197-1 Composition, specification and compliance criteria of cements, Praha: ČNI

- Application of GBFS in common cement
  - Combination of alkali activation and common hydration



Use of latent hydraulicity granulated blast furnace slag (GBFS)

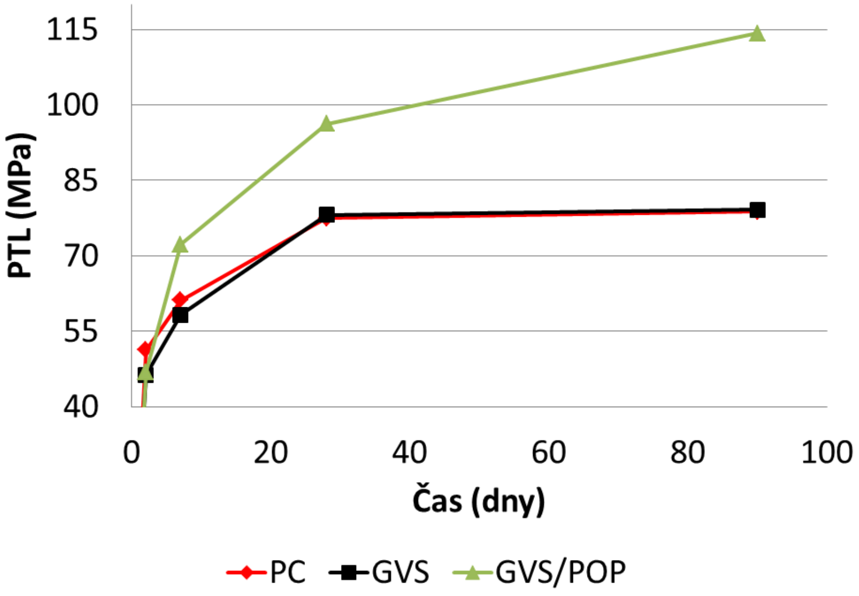
- Slag has an amorphous character



- Treatment process

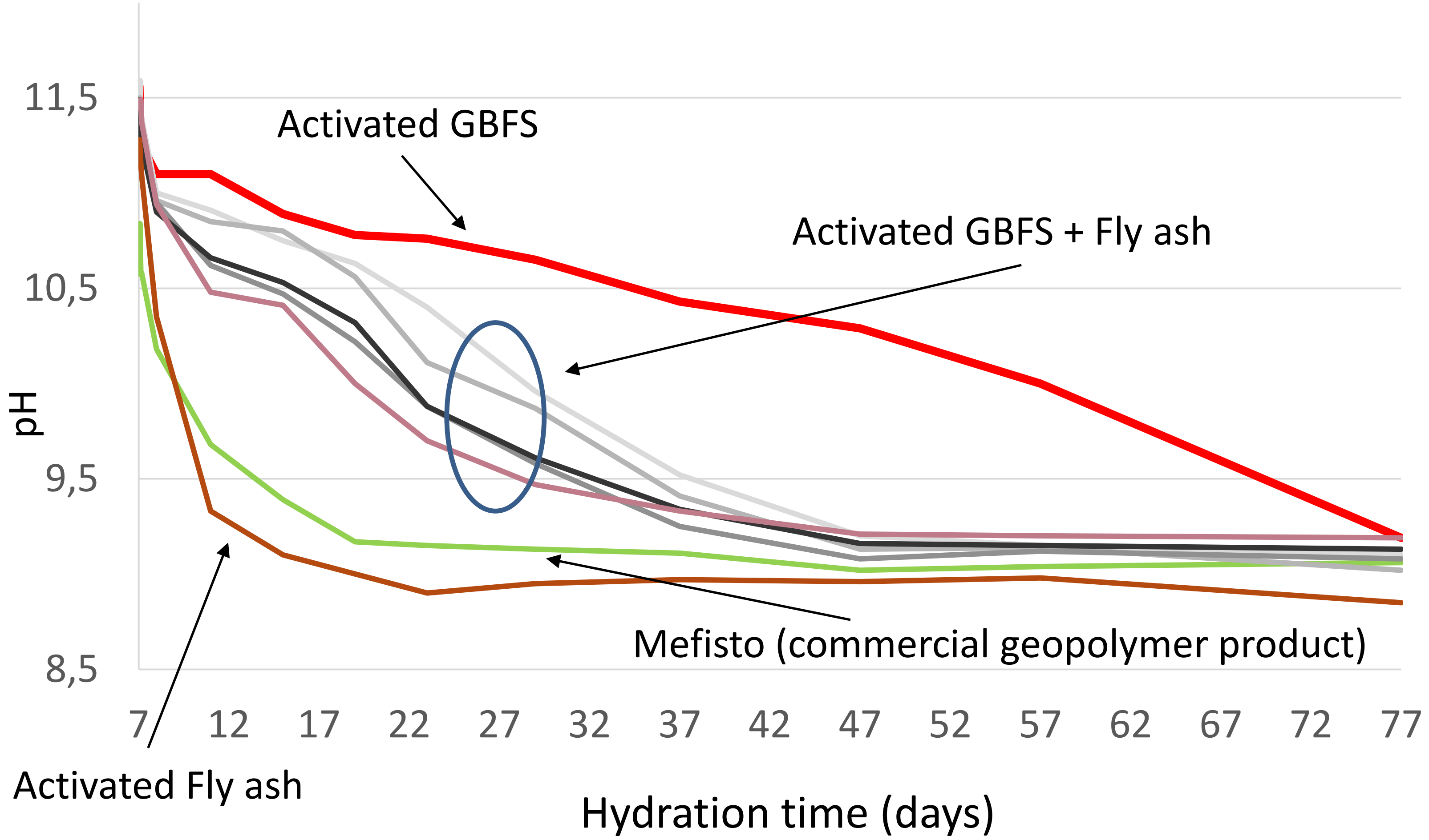
milling of GBFS → adding of agents → activation by water glass → hydration in wet storage

Sample	GBFS	Fly ash	CEM I 42,5
		(wt.%)	
GBFS	100	---	---
GBFS/FLY ASH	80	20	---
PC	---	---	100



Products of hydration
As a result of high CaO content the hydration products are similar to hydration products becoming from common cement
Addition of active Al_2O_3 increases representation of products so called geopolymeric type

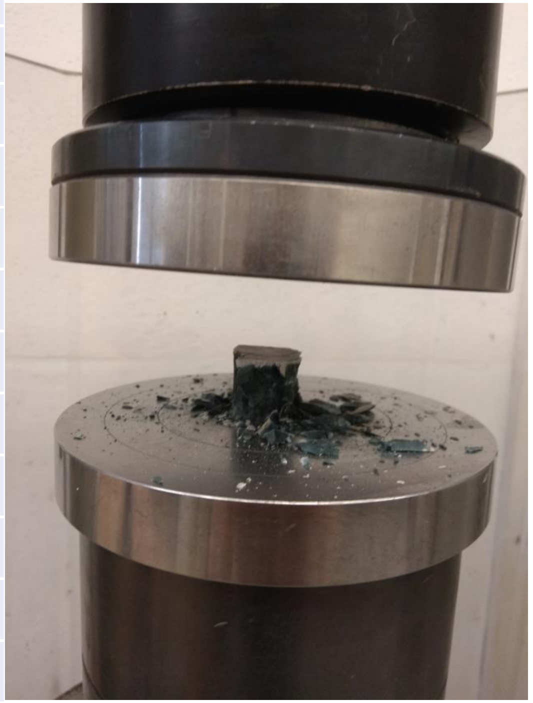
Indirect observation in progress of GBFS hydration



- Faster drop in pH → formation of geopolymeric products
- Slower drop in pH → formation of CSH phases
- Confirmed by NMR

Study of hydraulic properties of steel slags

sample	sample character	28 days – water activation	28 days – water glass activation
		(MPa)	
D19001	Granulated BF slag	3	54
D19005	Tandem furnace slag	4	16
D19006	Tandem furnace slag	5	24
D19007	Ladle slag	5	84
D19008	Ladle slag	5	48
D19017	Blended slag	3	18
D19022	Furnace slag	7	34
D19023	Furnace slag	12	45
D19024	BF aggregate	1	16
D19025	Casted converter slag	7	42
D19026	Converter slag	8	3
D19027	Furnace slag	8	48
D19028	Granulated BF slag	1	89
Average		**5**	**40**



Use of bonding ability of slags

- Treatment of grained (fine grained) materials to compact wholes

Strength of prepared briquettes up to 11 MPa, without content of conventional binder

Examples of lightweight samples

Lightweight sample from activated GBFS+Fly ash; 3,8 MPa; 722 **kg·m^{-3}; apparent porosity 72%**

Lightweight sample from furnace slag; 3,3 MPa; 930 **kg·m^{-3}; apparent porosity 60%**

Lightweight sample from Ladle slag; 2,3 MPa; 980 kg·m^{-3}; **apparent porosity 60%**

Thank You for attention.