[1.]Cătălin-Ioan ICHIM-BURLACU, [2.]Cezara-Liliana RAŢ,
[1.]Teodor HEPUŢ, [1.]Erika ARDELEAN

USING STEEL SLAGS IN ORDER TO OBTAIN MORTARS FOR CONSTRUCTION

[1.]Politehnica University Timişoara, Faculty of Engineering Hunedoara, Hunedoara, ROMANIA
[2.]Politehnica University Timişoara, Faculty of Automation and Computers, Timişoara, ROMANIA

Abstract: The global development strategy in the steel industry consists of implementing advanced technologies in order to increase the recovery rate of the by-products resulting from different technological flows. The main by-products that results from the steel industry are slags. The paper presents the results of the experimental investigations carried out in the laboratory on the use of steel slags in the manufacturing of mortars. The types of slag used were slags from an EBT electric arc furnace and slags resulting from the secondary treatment of steel in LF and VD plants. Slags of different granulations were used along with binders such as gypsum or SuperRigips in the manufacturing of different recipes of mortars. Samples of these mortars were subjected to a compression test 14 days after they were produced. The results of the test were correlated with the proportions of the constituents of the mortar recipes. A direction for further research can be established based on the technological analysis of the data.
Keywords: slag, ironworks, mortar, setting time

1. INTRODUCTION

The use of steel slags, in order to reduce production costs and also to minimize the amount of waste generated by the technological flows, is an area of interest in the research and production of steel. In order to reduce the impact caused by metallurgic slag waste, it is necessary to study their properties and the areas in which they can be exploited. The potential for slag recovery depends on their characteristics and the market demand.

The most important properties of slag taken into consideration when using them in a certain application are: chemical composition and mineralogical constituents, specific weight, granulation, color, allotropic shrinkage changes, thermal properties, sound absorption and noise absorption, sound transmission, durability, abrasion strength, corrosion strength, etc. [1].

The processing of metallurgical slag and development of materials that can be used in construction is a mutually advantageous activity for all the actors involved: it provides the guarantee of a total, cheap and environmentally safe disposal of the slag for steel producers, as well as lower purchasing and reduced building costs compared to traditional building industry technologies.

All these being considered, there are a multitude of uses of the slag, the main ones being shown in figure 1.

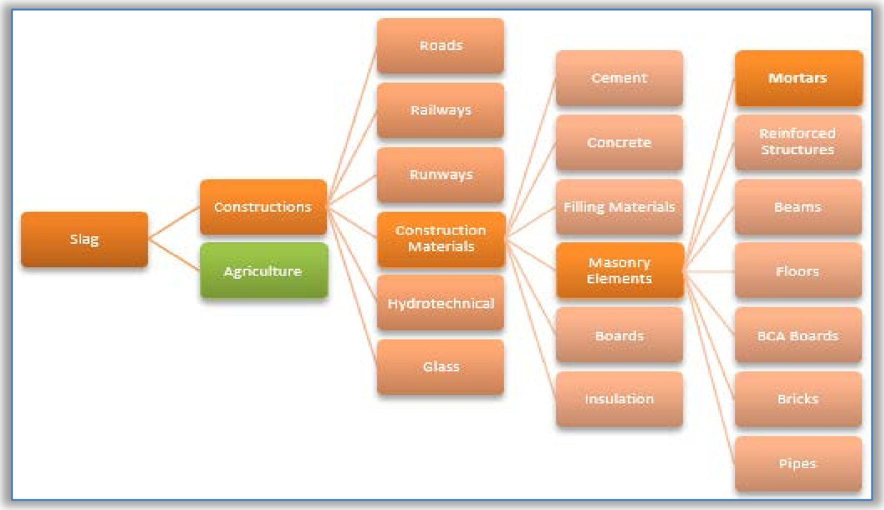

Figure 1. Domains of use of metallurgical slags

2. MORTARS

Mortars are well homogenized mixtures of binder, aggregates, water and various additives. The composition of a mortar represents the volumetric or gravimetric quantity of the mortar constituents and is expressed by the ratio of binder: sand or the required amount of components per cubic meter of mortar [2]. The doses of the components are established based on computational relationships or on the basis of norms, depending on the nature of the binder and the type of mortar [3]. Typical mortars are classified as follows:

a) by field of use [1, 3]:

- ≡ masonry mortars that serve to bond natural or artificial stones;
- ≡ plaster mortars that serve to embellish building elements;
- ≡ colored mortars that serve to decorate the walls of buildings;
- ≡ mortars for sound insulation;
- ≡ impermeable mortars that serve for waterproofing;
- ≡ anti-acid mortars that protect against acids.

b) by the nature of the binder [2, 3]:

- ≡ lime mortars: lime, lime-cement, lime-plaster;
- ≡ cement-based mortars: cement, cement-lime, cement-clay;
- ≡ gypsum(plaster) mortars: plaster, plaster-lime;
- ≡ clay-based mortars;
- ≡ slag based mortars.

c) by compressive strength. The compressive strength of mortars determined at 28 days is the mark of the mortar ($\mathrm{daN/cm^2}$) and is written as M followed by the respective strength (e.g. M4, M10, M25, M50, M100) [2, 3].

d) by apparent density [2, 3]:

- ≡ heavy mortars: with a specific apparent weight of $\rho_a > 1800\ \mathrm{kg/m^3}$;
- ≡ semi-gravel mortars: with a specific apparent weight of ρ_a = 1500-1800 $\mathrm{kg/m^3}$;
- ≡ light mortars: with a specific apparent weight of ρ_a = 1000-1500 $\mathrm{kg/m^3}$;
- ≡ very light mortars: with a specific apparent weight of $\rho_a < 1000\ \mathrm{kg/m^3}$.

e) by consistency [3]:

- ≡ fluid mortars;
- ≡ plastic mortars;
- ≡ viscous mortars.

Mortars are influenced by environmental conditions (temperature, humidity, air currents, etc.) depending on which the type of binder is chosen. For the less demanding parts of the construction, the basic binder in the preparation of mortars is the lime (cured, powder or crushed lime). Lime mortar is used for masonry in dry environment due to the hydraulic properties of lime. Mortars with mixed binders (cement lime and possible waterproofing admixtures) are used when working in a wet environments. Compact masonry materials (foundations, sockets) use cement (alone or mixed with lime or clay). When preparing mortars that are permanently found in a dry (air) environment, plaster is used (as such or with lime). In the preparation of mortars for porous stones (bricks) for ground-level air elements (up to three floors), clay is used [4, 2].

Aggregates exert a greater influence than the binder on the technical properties of mortars. The finer and larger the aggregate, the lighter and more porous the mixture becomes, but it requires more water and gains lower mechanical strengths. The most commonly used aggregate for mortar is sand. Mortars made with aggregates with a good granulometric composition harden slower and contract little. Contraction, i.e. the reduction of the mortar volume, occurs in cement mortars and results in cracks. This defect appears when the mortars are too loose and is rarely encountered in plaster mortars [4, 2, 5].

Plasticity (workability) is the property of the mortar to take any shape and size and to be easily molded. This property depends on the granulometric composition of the slag and the binder dosage and it does not increase by adding water, only by adding more fine aggregate and more binder [2].

Additives are substances that, admixed in small amounts in mortars, slow down the curing (setting) process and improve the workability of the fresh mixture: plasticizers, dyes, waterproofing substances, hydraulic substances, etc. The resulting mortar is hardened either by air or by water, depending on the nature of the binder. It must be noted that fast-setting mortars adhere less strongly than those with a slower cure [4, 2].

The mark of the mortar (4, 10, 25, 50 and 100) is determined on the basis of the minimum compressive strength taken 28 days after its preparation [6]. The compressive strength determined after 3 days of setting reaches only 25% of the mark of the mortar, while the one determined after 90 days can reach 30% higher than its mark. Lime mortars are the exception to the rule, having a setting time of 90 days, not 28, with a minimum compressive strength of 40 $\mathrm{daN/cm^2}$ (M4). At 28 days, lime mortars would have a minimum compressive strength of 20 $\mathrm{daN/cm^2}$ (M2). The storing conditions for mortars until testing depend on the nature of the binder (hydraulic and non-hydraulic) [2, 4, 7-10].

3. LABORATORY EXPERIMENTS

This paper explores the use of metallurgical slag as an aggregate, replacing sand or in combination with it. The metallurgical slag used for the preparation of the mortars should have a grain size of up to 7mm (0/1, 0/2, 0/4, 0/8mm).

These experiments were carried out in the Laboratory of Energy and Raw Materials of the Faculty of Engineering Hunedoara on mortars produced with steel slags.

The types of slag used in these experiments were basic steel slags from an EBT electric arc furnace and from the secondary treatment of steel in LF (Ladle Furnace) and VD plants (Vacuum Degassing station).

To ensure the required granulation for the production of the mortars, the slags were ground in a ball mill (Figure 2) and graded using the classification system shown in Figure 3.

Figure 2. Ball mill for grinding

The chemical composition of these slags is presented in Table 1 and the granulometric composition in Table 2. The chemical composition of the slag is determined by the needs of the specific technological step of steel production, so the physical characteristics of the slag vary depending on the conditions imposed by the technological process.

a) Apparatus for sorting the slag b) Detail on the sorting of the slag c) Slag ground to different grain sorts d) Slag with a granulation of 125µm

Figure 3. The granulometric sorting of the slag

Slag mortars are durable and have a high strength to weather conditions [3], being used for building elements subjected to strong erosion such as protective walls in hydropower plants. The paper presents the mechanical compressive strength of aggregates based on slag (LF and VD).

Table 1. Chemical composition of the slags

Slag type	Chemical composition (%)											CaO/SiO$_2$
	S	CaO	SiO$_2$	Al$_2$O$_3$	MnO	MgO	TiO$_2$	K$_2$O	Cr$_2$O$_3$	Fe$_2$O$_3$	Na$_2$O	P$_2$O$_5$	
EAF	0.112	37.15	20.63	9.03	4.11	11.43	0.48	0.025	1.02	14.63	0.230	0.384	1.80
LF	0.099	29.38	19.14	7.21	4.05	7.89	0.41	0.067	1.48	27.87	0.351	0.433	1.54
VD	0.097	28.10	17.98	6.1	4	5.86	0.38	0.039	1.1	18.27	0.21	0.296	1.46

Table 2. Granulometric composition of the slags

Slag type	Granulometric composition (%)			
	>125µm	112-125µm	40-112µm	< 40µm
EAF type slag	50.00	34.82	13.27	1.91
LF type slag	50.00	33.66	13.62	2.72
VD type slag	50.00	33.30	14.32	2.38

a) Prism test specimens of 40x40x100mm b) Cubic test specimens 7.07x7.07x7.07mm

Figure 4. Test specimens

The tests were performed on prism test specimens of 40x40x100mm of hardened mortar (Figure 4.a) and cubic test specimens (Figure 4.b) with a 7.07cm side, the lower part of which is replaced with a porous support. The prismatic specimens contain 200g of mortar. The compressive strength is determined by the force of compression on an area of 1cm2. This force, determined using the apparatus shown in Figure 5.a varies over time, increasing as the mortar hardens [3]. Aspects of cracks during the compression test are shown in Figures 5.b and 5.c.

The first lot of mortars was prepared from LF slag of a certain granulation and construction plaster ($2CaSO_4\ H_2O$) as a binder. Setting started after 3-4 minutes and ended within a maximum of 30 minutes. The amount of water required for a workable mortar is 50-60% of the weight of the plaster. Plaster is sensitive to humidity and is not used outside or in humid areas. The apparent density of the plaster is $900\mathrm{kg/m^3}$ [4]. The recipes and the qualitative characteristics of the specimens are presented in Table 3 and graphically in Figure 6.

a) Apparatus for determining the compression strength
b) Prism test specimen being tested on the machine with cross-cracks
c) Prism test specimen being tested on the machine with splitting cracks

Figure 5. Testing the prism specimens

Table 3. Tests on mortars with LF slag (125µm) and plaster

No.	Component/ Property	Recipe No.							
		1	2	3	4	5	6	7	8
1a	Slag quantity (g)	193	183.33	176.65	170	185	175	165	155
2a	Plaster quantity (g)	7	16.67	23.35	30	15	25	35	45
3a	Total (g)	200	200	200	200	200	200	200	200
4a	Water quantity (g)	86.4	123	118	126.7	112.11	101.88	98.41	95.3
1b	Slag quantity (%)	96.5	91.665	88.325	85	92.5	87.5	82.5	77.5
2b	Plaster quantity (%)	3.5	8.335	11.675	15	7.5	12.5	17.5	22.5
3b	Total (%)	100	100	100	100	100	100	100	100
4b	Water quantity (%)	43.2	61.5	59	63.35	56.055	50.94	49.205	47.65
5	Compression force (daN)	800	770	800	870	830	1020	1550	2220
6	Surface ($\mathrm{cm^2}$)	16	16	16	16	16	16	16	16
7	Compression strength at 14 days ($\mathrm{daN/cm^2}$)	50	48.125	50	54.375	51.875	63.75	96.875	138.75
8	Compression strength at 14 days ($\mathrm{N/mm^2}$)	5	4.8125	5	5.4375	5.1875	6.375	9.6875	13.875

Table 4. Technical Data SuperRigips [11]

Standard	CE conform SR EN 13963	Adherence	Approx. 0.4$\mathrm{N/mm^2}$
Class	3B	Strength to bending	Approx. 3.1$\mathrm{N/mm^2}$
Composition	White plaster, aggregates and additives	Compression strength	Approx. 6.2$\mathrm{N/mm^2}$
Fireproof	A1	Setting time/Use time	8-15min/min. 40min
Fineness	99% sub 200µm	Blend ratio	5kg powder /4l water
Density	Aprox. 640g/l	Powder use	0.3kg/mp/joint

Table 5. Tests on mortars with LF slag (125µm) and SuperRigips

No.	Component/ Property	Recipe No.		
		1	2	3
1a	Slag quantity (g)	183.33	176.66	170
2a	Superrigips quantity (g)	16.66	23.32	30
3a	Total (g)	200	200	200
4a	Water quantity (g)	115.46	115.43	105.22
1b	Slag quantity (%)	91.669	88.339	85
2b	Superrigips quantity (%)	8.331	11.661	15
3b	Total (%)	100	100	100
4	Water quantity (%)	57.732	57.720	52.61
5	Compression force (daN)	700	720	900
6	Surface ($\mathrm{cm^2}$)	16	16	16
7	Compression strength at 14 days ($\mathrm{daN/cm^2}$)	43.75	45	56.25
8	Compression strength at 14 days ($\mathrm{N/mm^2}$)	4.375	4.5	5.625
9	Mortar quantity (g)	199.99	199.98	200

SuperRigips has also been tested as a binder (the second lot). SuperRigips is a plaster-like substance but more workable, being recommended for filling joints and finishing plaster boards. The SuperRigips technical data, shown in Table 4, is given for a temperature of 23°C and an air humidity of 50 ± 5% [11].

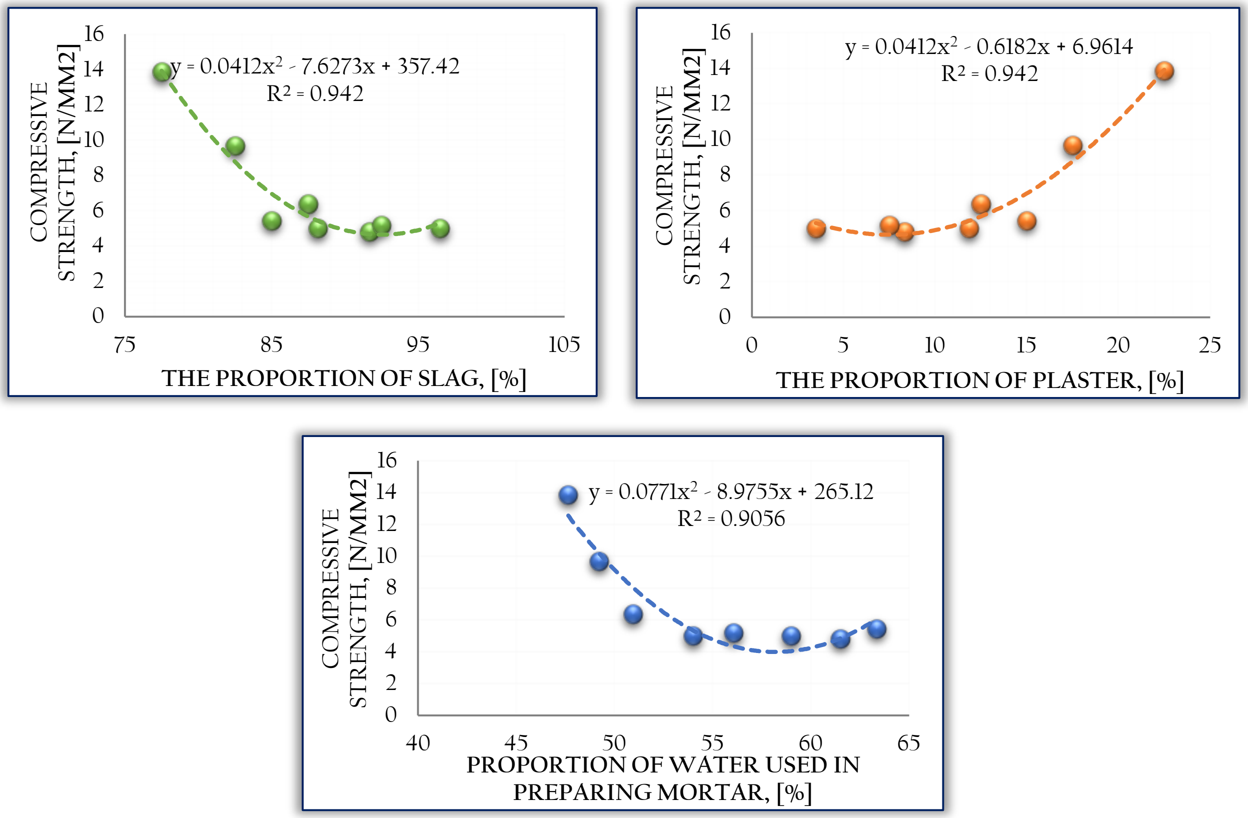

Figure 6. Compression strength at 14 days for mortars with LF slag (125μm) and plaster

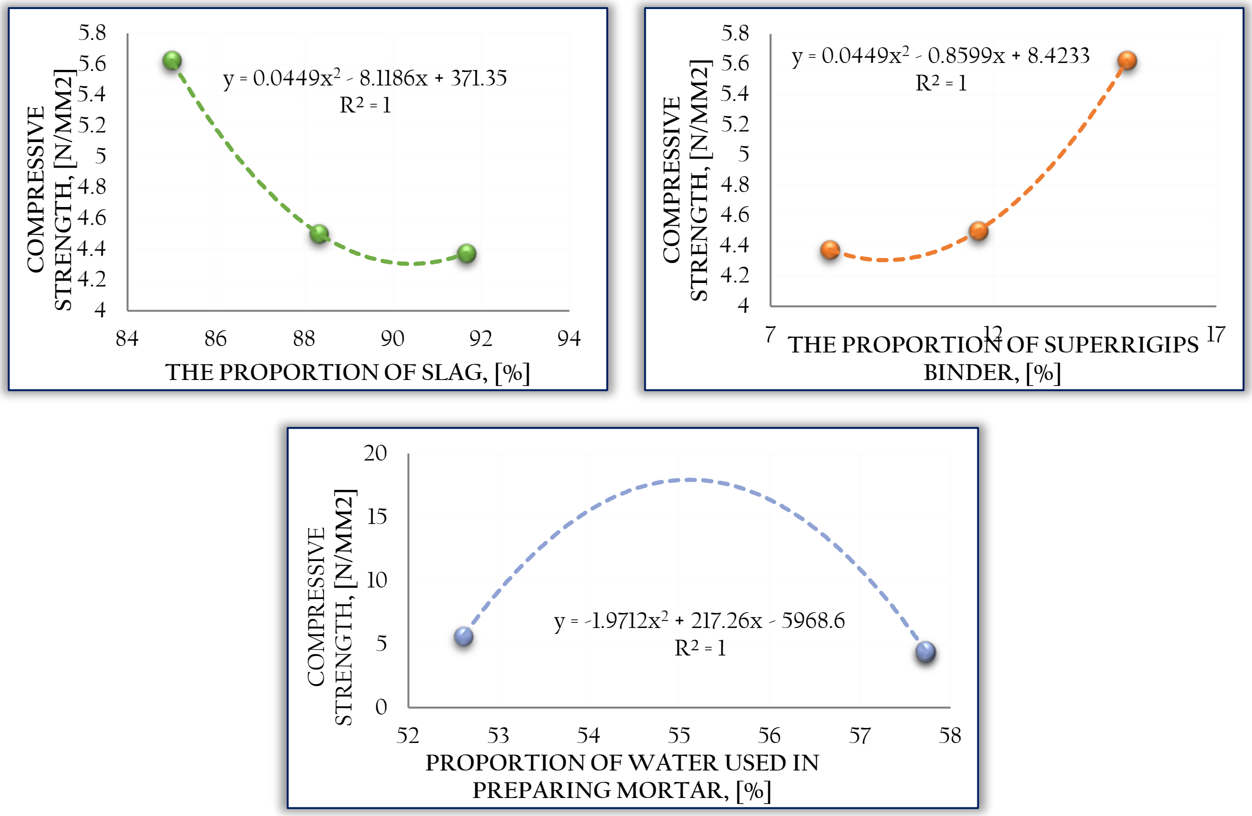

Figure 7. Compression strength at 14 days for mortars with LF slag (125μm) and SuperRigips

Table 5 presents the results of the LF and SuperRigips slag mortar tests, and Figure 7 is the graphical representation of the correlations between the compressive strength determined at 14 days (setting time) and the proportion of the components in the recipe. With a larger addition of SuperRigips, the mortar hardens faster and the working time is reduced. With a lower addition of SuperRigips, the compression strength decreases, but working time increases. There is a certain composition ratio (% slag /% SuperRigips) to obtain a more elastic, more workable mortar.

LF slag of smaller granulation (112µm) and SuperRigips were also used to make mortars, the results of this being presented in Table 6 - the third mortar lot. The graphical dependencies of the compressive strength of the specimens and the proportion of components used are shown in Figure 8.

Table 6. Tests on mortars with LF slag (112 µm) and SuperRigips

No.	Component/ Property	Recipe no.			
		1	2	3	4
1a	Slag quantity (g)	170	150	130	110
2a	SuperRigips quantity (g)	30	50	70	90
3a	Total (g)	200	200	200	200
4a	Water quantity (g)	104.59	98.7	97.92	102.47
1b	Slag quantity (%)	85	75	65	55
2b	SuperRigips quantity (%)	15	25	35	45
3b	Total (5)	100	100	100	100
4b	Water quantity (%)	52.295	49.35	48.96	51.235
5	Compression force (daN)	342	420	1285	1290
6	Surface (cm^2)	16	16	16	16
7	Compression strength at 14 days (daN/cm^2)	21.375	26.25	80.3125	80.625
8	Compression strength at 14 days (N/mm^2)	2.1375	2.625	8.03125	8.0625

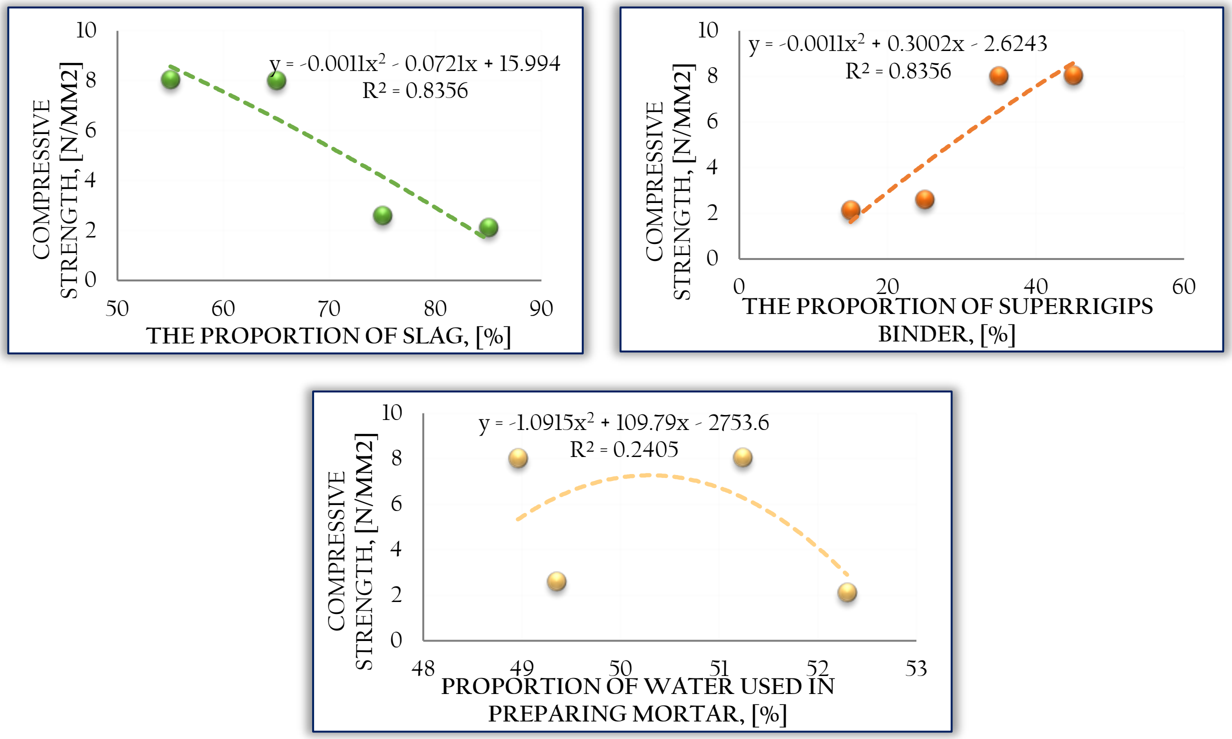

Figure 8. Compression strength at 14 days for mortars with LF slag (112µm) and SuperRigips

Table 7. Tests on mortars with VD slag (<7 mm) and plaster

No.	Component/ Property	Recipe no.			
		1	2	3	4
1a	Slag quantity (g)	185	165	140	110
2a	Plaster quantity (g)	30	50	70	90
3a	Total	215	215	210	200
4a	Water quantity (g)	57.1	78.6	82.8	75
1b	Slag quantity (%)	86.046	76.744	66.667	55
2b	Plaster quantity (%)	13.954	23.256	33.333	45
3b	Total	100	100	100	100
4b	Water quantity (%)	26.558	36.558	39.428	37.5
5	Compression force (daN)	1140	320	450	1070
6	Surface (cm^2)	16	16	16	16
7	Compression strength at 14 days (daN/cm^2)	71.25	20	28.125	66.875
8	Compression strength at 14 days (N/mm^2)	7.125	2	2.8125	6.6875

The fourth lot of mortars was made using VD slag and plaster. The data are summarized in Table 7 and the graphical dependencies and analytical correlations are shown in Figure 9.

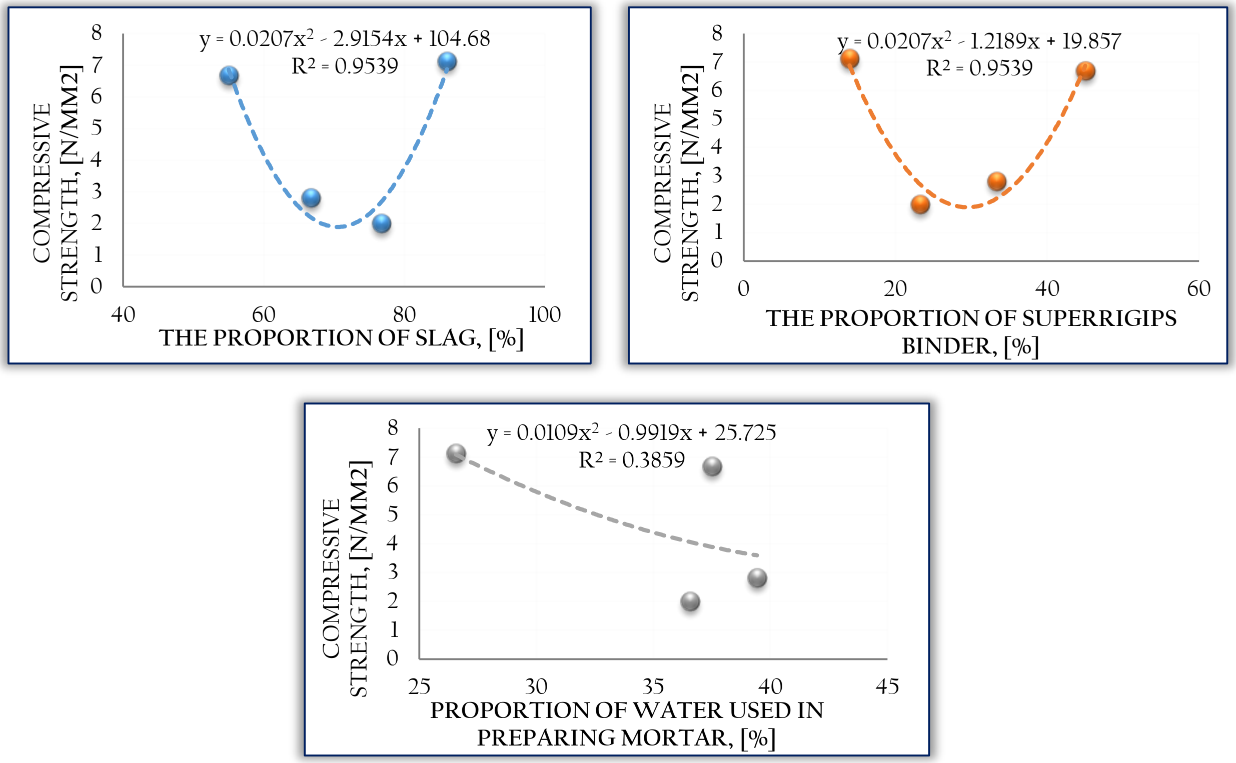

Figure 9. Compression strength at 14 days for mortars with VD slag (<7 mm) and plaster

4. FINAL RESULTS AND CONCLUSIONS

A total of 21 recipes with slag-based aggregate and plaster and SuperRigips as binders were tested for compressive strength in laboratory conditions after setting for 14 days. These are the specific conclusions on each batch of mortars:

- The results from analyzing the data presented in Table 3 and the correlations in Figure 6 are that an increase of the proportion LF slag in the range of 77.5-96.5%, together with a decrease of 22.5- 3.5% in the proportion of plaster leads to a decrease in the compressive strength of the mortar from 13.875$\mathrm{N/mm^2}$ to 4.8125$\mathrm{N/mm^2}$. Regarding the addition of water, an increase of 47-52% leads to a slight decrease of the compressive strength. An increase over the upper limit has no significant influence.
- The results from analyzing the data presented in Table 5 and the correlations in Figure 7 for the mortar made with 125µm LF slag and SuperRigips binder, were that a proportion of the 85% slag and 15% SuperRigips lead to the best results. Regarding the addition of water, for a proportion of 52.61%, the compressive strength was 5.625$\mathrm{N/mm^2}$.
- For mortars produced using 112µm LF slag and SuperRigips (Table 6 and Figure 8), the best results (compressive strength) were obtained for the mortars with the following compositions: 65% slag, 35% SuperRigips (recipe 3) and 55% slag, 45% SuperRigips (recipe 4). The compressive strength for recipe 3 was 8,031$\mathrm{N/mm^2}$ and for recipe 4 8,063$\mathrm{N/mm^2}$. The addition of water (based on total component ratio-100%) was 49%, respectively 51%.
- For the fourth batch, produced with VD slag and plaster, the best strength was determined in recipes 1 and 4 with the following proportions of solid components: 86.04% VD slag and 13.95% plaster and 55% VD slag and 45% plaster, with water additions of 26.55% and 37.5% respectively.

From the observations obtained during the experiments and the analysis of the results, the following can be concluded:

- slags resulting from the refining of steels in LF-type (heat-in-waste) processing facilities can be used with good results;
- it is necessary to have a certain composition ratio (% slag / plaster% or slag% / SuperRigips%) for a mortar to be more elastic, more workable and to have a certain compressive strength;
- by increasing the weight of plaster in the recipe, the resulting mortar hardens faster, has a higher compressive strength (strength increases with plaster dosing), but the working time decreases;
- the fineness of the slag grinding also influences the strength of the mortar, meaning that very fine granulation slags, relative to the medium grain ones, increase the strength in the first days after casting, but the strength becomes the same after 28 days;

— the amount of water added in addition to the minimum required quantity increases the workability of the mortar, but leads to a decrease in strength and increased permeability.

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