

Scientific and Technological Innovations in the Reprocessing Metal-Containing Industrial Waste and Industrial Waste of Polymeric Materials by Metallurgical Methods

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Abstract: The paper studies the mechanism of using baling charge and modifying materials, including metal-containing industrial waste and man made waste of polymer products introduced as bales into the melt. This process is accompanied by pyrolysis of polymers and homolytic cleavage of bonds with hydrogen and carbon atoms (hydrocarbon radicals) formation, reducing iron from new charge materials and other metals, from cheap additives that provide modification, including the centers formed in the melt as a result of chemical reactions. The method secures technological strength and indestructibility of bales during transportation, heating and melting.

Keywords: Iron-Carbon Alloys, Alloying, Industrial Metal-Containing Waste, Structure Formation, Material Balance of Melting, Morphology of Non-Metallic Inclusions

1. Introduction

Due to the gradual depletion of the exploited iron ore deposits, decrease of scrap metal collection, increase of the cast iron cost and railway fares for its delivery, the metallurgy had to search for alternative materials [1].

A number of technological processes are accompanied by formation of a significant amount of metal-containing waste [1-4], mainly as oxides (scale, rust, sludge, grinding scrapes, wastes of facing materials, etc.). When using known reducing agents (carbon as coke and graphite dust, powdered charcoal), a sufficient degree of metal extraction is not provided [5-6]. The described technology was not widely used in the smelting of iron-carbon alloys. This is due to the lack of effective reducing agents and insufficient reactivity of carbon and silicon to a number of oxides. The degree of alloying elements recovery from slag is determined by the reaction of alloying elements with iron oxides.

Being pioneered at the Belarusian state technological University [7-8] the methods of iron and steel smelting suggest using waste polymeric materials from chemical compounds for metals reduction and providing the

reprocessing of metal-containing waste by metallurgical methods [9-11]. It should be noted that about 50 billion tons of plastic have been produced since 1950s, 80% of which is not reprocessed and is disposed of at landfills (about 50 million tons per year).

A comprehensive solution to the problem involves the use and reprocessing of industrial waste and semi-finished products related to mechanical engineering [1, 12] at all stages of metallurgical processing: melting of baling charge materials of metal-containing industrial waste, which are mainly in the form of oxides: oxides scale, rust, sludge, grinding scrapes, including organic pollutants, wastes of facing materials, waste catalysts of chemical, petrochemical, mineral fertilizers production industries, which contain Al_2O_3 , SiO_2 , CaO as well as nickel, molybdenum, cobalt, copper, chromium and tungsten oxides; semi-finished products related to mechanical engineering industries (titanium oxides, vanadium and other elements used as raw materials in the glass industry); non-recoverable high-polymer compounds (not prone to coke formation during thermal destruction (polyolefins, aliphatic polyamides), or prone to coke formation (polyphenylenes, polyamides,

polybenzimidazoles), as well as non-recoverable elastomers (silicone, acrylic rubbers, rubber based on ethylene propylene, chloroprene, polysulfide rubbers, butyl rubber, polyurethane), including rubber products containing 15-35% of textile or metal reinforcing materials containing chemically bound or structurally free carbon [1, 7-8]; finishing melts by direct, direct surface alloying methods and modification, provided by reducing metals by atomic hydrogen and carbon, formed during the homolytic cleavage of bonds in the pyrolysis of polymers introduced in bales together with metal-containing waste, in the melt, creating a reducing medium and providing modification [1, 10-11, 13], accompanied by chemical interaction of the components of additives with individual elements of the crystallizing substance, including the centers, formed in the melt.

The proposed method is aimed at creating a fundamentally new technology of metallurgical processing of iron-containing industrial waste (scale, iron-containing dust, sludge, iron-containing sludge) by baling them together with man-made waste polymers, using as reducing agents of the compounds formed during pyrolysis of polymers and homolytic cleavage of bonds. This technology will save material and energy resources, reduce harmful emissions and improve the quality characteristics of alloys.

2. Composition and Structure of Original Materials

Iron-containing man-made waste

The investigation of scale and other components of the bales was carried out by scanning electron microscopy with

microscope JSM-5610LV (firm JEOL, Japan) with a system of electron probe energy dispersive x – ray analysis. The microcomposition of inclusions was determined by the method of electron – probe EDX analysis on the detector IED 2201.

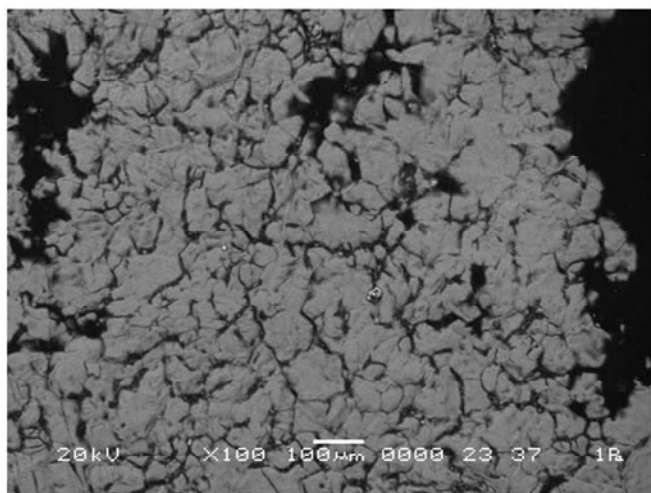
The scale is presented by exfoliated and fragmented flakes up to 2 mm thick (figure 1).



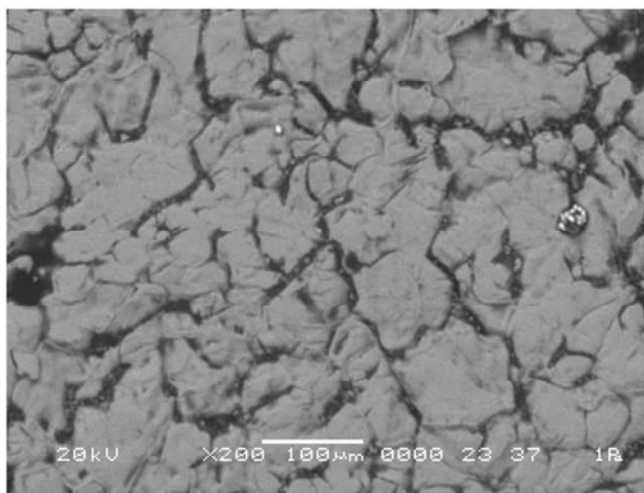
Figure 1. Appearance of lump scale from steel feed after reheating furnace.

The studies of scale by scanning electron microscopy (SEM) can detect light (oxide) and dark (carbon) areas of scale (figure 2).

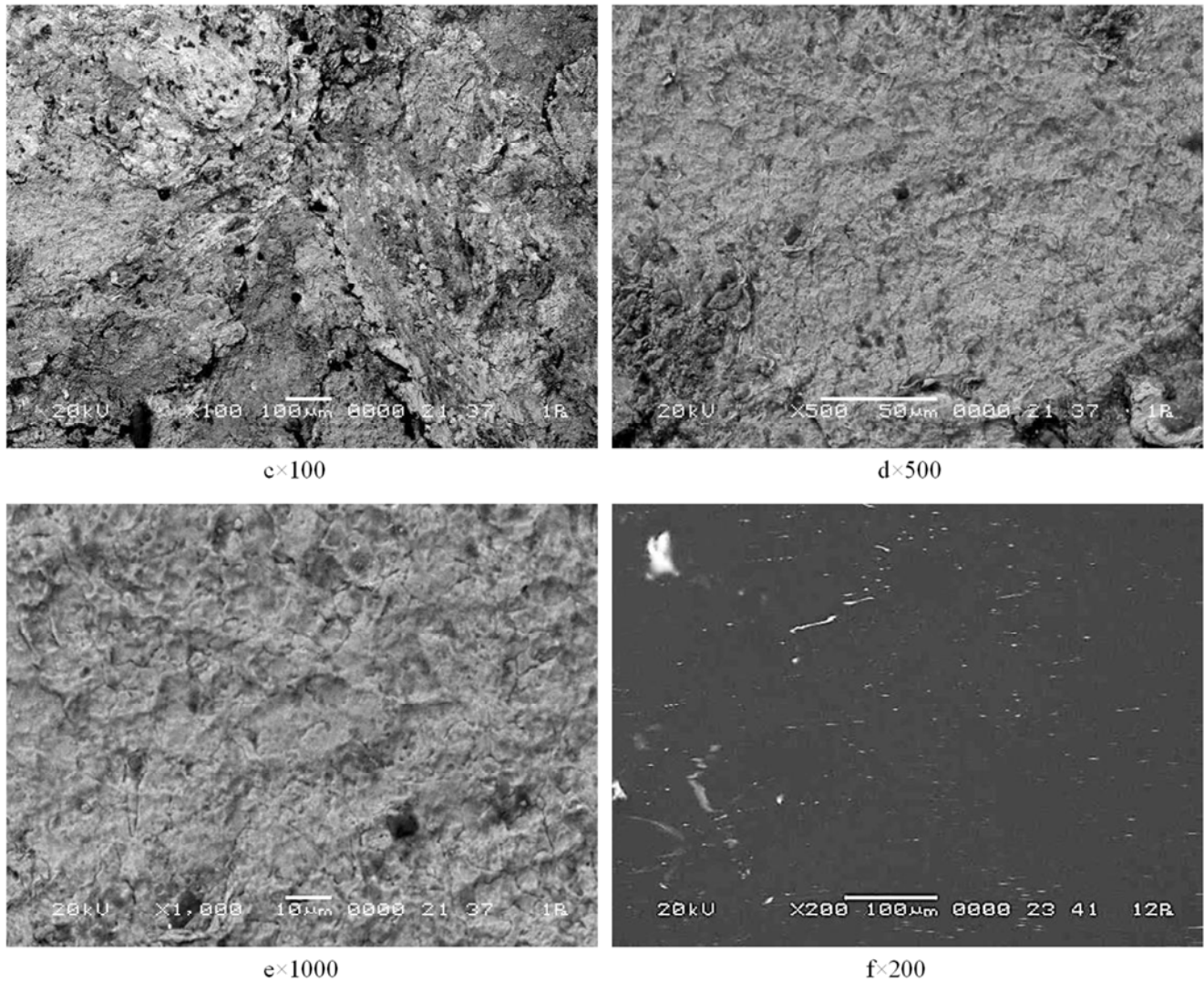
Microcomposition (table 1) of the scale, determined by the method of electron probe EDX analysis on the detector ID 2201, demonstrates iron oxides (figure 2c, 2d) and carbon-containing (figure 2f) areas of scale.



a×100



b×200



a - type of light (oxide) and dark (carbon) areas of the structure; b, c, d, e-oxide areas of the structure; f-carbon-containing areas of the structure.

Figure 2. Scale structure (investigated by scanning electron microscopy) at various magnifications.

Waste elastomers. Ground tyres sized no more than $10 \times 10 \times 10$ had the following approximate chemical composition (% wt): C (chemically bounded comp.)– 35.70; C (soot)– 30.77; C (total input) – 66.47; H₂ – 17.17; S – 1.50; Zn – 1.59; Cu, Ti, Al, Co, Fe, Pb – insignificant amount. The ground tyres were introduced as reducing agents in the composition of charge bales with scale.

Table 1. The chemical composition of the components of the scale.

areas of scale	Component composition, % wt.										
	O	C	Al	Si	P	S	Ca	Cr	Mn	Ni	Fe
light (oxide) areas (figure. 2c)	10.11	-	0.31	0.62	-	0.09	0.35	0.01	1.27	0.30	86.96
light (oxide) areas (figure. 2d)	6.74	-	0.80	1.55	0.26	0.01	0.80	-	1.69	0.30	87.85
dark (carbon-containing) areas (figure 2f)	-	80.43	1.45	0.34	-	0.31	0.52	0.29	-	-	16.16

3. Technologies for Casting Materials Production from Metal-Containing and Polymer Industrial Waste

An important trend in saving metals that are components of alloying and modifying additives is their extraction from waste and semi-finished products of related industries.

When implementing the technology, the grounded products from high-polymer materials, together with metal-containing industrial waste are introduced into the metal melt in the form of bales formed by a binding substance.

3.1. Charge Materials from Metal-Containing and Polymeric Industrial Waste

According to the developed technology, the bales were

formed by peg rammer with scale, waste of polymeric materials; cement was used as a binder (the composition of the bales is given in section 4).



Figure 3. Bales appearance.

When bales are immersed (Figure 3) in the melt, pyrolysis of polymers occurs, which is accompanied by a homolytic bonds cleavage with the formation of hydrogen and carbon atoms (hydrocarbon radicals), creating a reducing medium that provides both deoxidation of iron and recovery of metals from oxides.

3.2. Method of Metallurgy Bales Production

The most cost-effective and environmentally-friendly is the "cold" baling. At the stage of industrial testing, development of charge materials bales from man-made waste can be carried out manually using a technology similar to the technology of manufacturing concrete blocks.

Mechanized baling process involves using stamp, turret, roller presses. However, these methods have low performance, complexity of equipment, limitations in size, etc. The demerits of previously adopted manufacturing technologies are completely eliminated at vibration molding lines for construction materials production. Nevertheless, it is necessary to take into account the economic expenditure, and the output of the recycled waste.

3.3. Binders for Bales

Having analyzed the bales performance with various binders (lime, liquid glass, magnesium, slag-alkaline binder, etc.) and the manufacturability of their use in production, the most cost-effective use is that of Portland cement. The advantages of Portland cement include:

1. the ability to achieve quickly (up to 16 hours) the required operational strength;
2. low energy consumption to accelerate the set of bales strength (temperature $t \sim 50^\circ\text{C}$);
3. the start of cement setting (adhesive activity) occurs in about 2 hours, which provides the possibility of "quiet" equipment maintenance, excluding "jamming" of

machines and mechanisms during a short emergency stop;

4. cement is not as chemically aggressive as liquid glass or lime, which requires special skills of personnel and special transport and storage equipment;
5. Portland cement is a hydraulic binder, i.e. retains its properties under air-dry as well as humid conditions, unlike air binders (lime, magnesia binder, liquid glass, etc.);
6. high specific surface area of cement allows sufficient adhesion of the particles of the main components of the bale with minimal consumption of the binder;
7. under the influence of vibration, the cement is subjected to "liquefaction" to provide a dense structure of the bale in the molding process without creating internal stresses, unlike the impact of high pressure;
8. the process of cement hydration occurring in the heat treatment chambers is exothermic; when cement is hardened, heat is released in the amount of 40-80 cal /g (depending on the cement type), i.e. each ton of briquette in the strengthening process is an additional source of heat in the amount of 4000-8000 kcal;
9. the market of Portland cement suppliers is quite large, i.e. this binder belongs to the common ones, which is a significant factor in the organization of high-performance briquette factories.

The disadvantage of Portland cement is the sulfur content in the amount of 0.4-1.2%. However, it should be noted that in the composition of the briquette cement does not exceed 10%, i.e. each ton of the briquette adds to the metallurgical charge 0.04-0.12% S, which is comparable to the amount of sulfur in the traditional carbon-containing material. Portland cement is a complex material obtained by backing and joint grinding of clay and limestone. Its composition includes the following oxides: CaO - 62-67%; SiO₂ - 20-23%; Al₂O₃ - 4-8%; Fe₂O₃ - 1-4%; MgO - 0.5-5%; SO₃ - 1-3%; K₂O + Na₂O - 0.5-1%. The behavior of Portland cement at high (over 1000°C) temperatures requires further study. The presence of such oxides as CaO, MgO in the cement composition gives grounds for the assumption that the sulfur will remain in the slag, and will not pass into the metal melt. The process of Portland cement hardening keeps intense for 28 days, and then slows down. Depending on the hardening time of Portland cement, various crystallohydrates are formed. Therefore, determining the terms of using briquettes while observing the optimal ratio "strength-melting point" for melting also requires additional study.

In addition, it should be said about such a variety of cements as alumina cements. Having all the physical and mechanical properties typical of Portland cement, alumina cements have significant differences in chemical composition. The content of basic oxides in alumina cement: CaO - 35-40%; SiO₂ - 4-8%; Al₂O₃ - 35-44%; FeO - 4-10.5%; MgO - 0.5-5%; SO₃ - 0.01-0.32%; K₂O + Na₂O - 0.1-1.2%. Using alumina cement as a binder will limit the amount of sulfur in the briquette. However, it should be borne in mind that alumina cement is a scarce material and

its price is 5 times higher than that of Portland cement.

Considering the binders for the production of metallurgical briquettes, it is important to mention the slag-alkali binder. It would seem that the use of slag as a binder for metallurgical briquettes is the most appropriate one. However, sulfur is present in approximately equal amounts in the composition of slag as well as in Portland cement. But the main reason that limits the use of slag as a binder is the high energy costs for slag activation. Slags are active if their specific surface

area is more than 4500 cm²/g. If compared, the duration of slag grinding is 2-2.5 times longer than the duration of cement clinker grinding.

Taking into account all the above, we can conclude about the advantages of using Portland cement as a binder in the production of metallurgical briquettes, which does not exclude the use of other types of binders (lime, liquid glass, magnesium, slag-alkali binder, etc.) for solving special problems.

4. The Behavior of the Melt Components When the Bales of Iron-Containing Waste and Waste Elastomers (Grouded Tyres) Are Introduced

4.1. The Composition of the Charge in the Smelting of Cast Iron with the Introduced iron-Containing Waste and Waste Elastomers (Grouded Tyres) Bales

Table 2. Chemical composition of the introduced charge bales with iron-containing waste and waste elastomers (grouded tyres) bales.

Melting	Weight of the initial liquid metal, kg	Introduced blocks total composition:
1	482	Introduced: scale 7 kg cement 1.7 kg rubber (pieces of tyres) 0.35 kg
2	462	Introduced: scale 14 kg cement 3.4 kg rubber (pieces of tyres) 0.75 kg

4.2. Chemical Composition and Material Balance of Melting After the Introduction of Iron-Containing Waste and Waste Elastomers (Grouded Tyres) Bales

Table 3. Chemical composition of cast iron melting before and after the introduction of iron-containing waste and waste elastomers (grouded tyres) bales.

Melting conditions	Elements Content, % wt.									
	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Ti
Original composition	3.50	2.15	0.328	0.108	0.039	0.092	0.051	0.005	0.077	0.007
Introduced: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	3.50	1.90	0.278	0.110	0.034	0.091	0.054	0.005	0.077	0.006
Introduced: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	3.44	1.48	0.210	0.112	0.045	0.083	0.055	0.005	0.078	0.004

Table 3. Continued.

Melting conditions	Elements Content, % wt.						Mechanical characteristics	
	V	Co	B	As	Sn	Zn	HB(5/750/10), Mpa	σ_B , Mpa
Original composition	0.009	0.006	0.0006	0.004	0.002	0.005	1790 1560	162.0168 .0
Introduced: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	0.008	0.006	0.0007	0.003	0.003	0.003	1970 2070	205.0 199.0
Introduced: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	0.007	0.006	0.0006	0.004	0.003	0.003	2410 2410	240.0 235.0

Since the structure is unbleached, carbon was determined by coulometry, other elements were determined spectrally.

Table 4. Material balance of melting after the introduction of iron-containing waste and waste elastomers (grouded tyres) bales.

Melting number, №	Original chemical composition of cast iron before the blocks were introduced, % wt	Element composition of the blocks	Mass of the introduced elements, g			Chemical composition of the slag, wt %	Chemical composition of cast iron after introducing blocks with scale and polymer, wt. %
			With scale	With polymer	With cement		
1	2	3	4	5	6	7	8
	C – 3.50; Si – 2.15; Mn – 0.328; P – 0.108; S – 0.039; Cr – 0.092; Ni – 0.051; Mo – 0.005; Cu – 0.077; Ti – 0.007;	scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	C – 0 Fe – 5600 Si – 35 Mn – 105 S – 3,5 Cr – 0,7 Ni – 2 Al – 3,5	C – 231 S – 5 Zn – 5	Fe – 25 Si – 464 Al – 85 Mg – 43 Ca – 697	C – 6.35; Si – 21.05; Mn – 10.22; P – traces; S – 0.12; Cr – 1,3; Ni – 0.17; Mo – traces; Cu – traces; Ti – 0.10;	C – 3.50; Si – 1.90; Mn – 0.278; P – 0.110; S – 0.034; Cr – 0.091; Ni – 0.054; Mo – 0.005; Cu – 0.077; Ti – 0.006;

Melting number, №	Original chemical composition of cast iron before the blocks were introduced, % wt	Element composition of the blocks	Mass of the introduced elements, g			Chemical composition of the slag, wt %	Chemical composition of cast iron after introducing blocks with scale and polymer, wt. %
			With scale	With polymer	With cement		
2	V – 0.009; Co – 0.006; B – 0.0006; As – 0.004; Sn – 0.002; Zn – 0.005	scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres) kr	C – 0 Fe – 11200 Si – 70 Mn – 210 S – 7 Cr – 0.14 Ni – 4 Al – 7	C – 495 S – 10 Zn – 10	Fe – 50 Si – 928 Al – 170 Mg – 86 Ca – 1394	V – traces; Co – traces; B – none; As – traces; Sn – traces; Zn – traces; O – 31.51; Al – 2.21; Na – 0.43; Mg – traces; K – 0.17; Ca – 7.00; Pb – 0.22; N – none; Fe – 27.26	V – 0.008; Co – 0.006; B – 0.0007; As – 0.003; Sn – 0.003; Zn – 0.003
	C – 3.50; Si – 1.90; Mn – 0.278; P – 0.110; S – 0.034; Cr – 0.091; Ni – 0.054; Mo – 0.005; Cu – 0.077; Ti – 0.006; V – 0.008; Co – 0.006; B – 0.0007; As – 0.003; Sn – 0.003; Zn – 0.003					C – 8.83; Si – 19.11; Mn – 4.49; P – 0.02; S – traces; Cr – 0.07; Ni – traces; Mo – traces; Cu – traces; Ti – traces; V – 0.09; Co – 0.38; B – none; As – 0.94; Sn – 0.40; Zn – traces; O – 34.60; Al – 2.09; Na – 0.11; Mg – traces; K – 0.15; Ca – 6.55; Pb – traces; N – none; Fe – 27.26	C – 3.44; Si – 1.48; Mn – 0.210; P – 0.112; S – 0.045; Cr – 0.083; Ni – 0.055; Mo – 0.005; Cu – 0.078; Ti – 0.004; V – 0.007; Co – 0.006; B – 0.0006; As – 0.004; Sn – 0.003; Zn – 0.003

The nature of changes in the slag microcomposition, structure and density after the bales with iron-containing waste and waste elastomers (grounded tyres) were introduced.

Comparison of the slag structure (figure 4, 5), density (table 5), composition and microcomposition of inclusions (table 6, figure 5) indicate the efficiency of processing metal-containing waste.

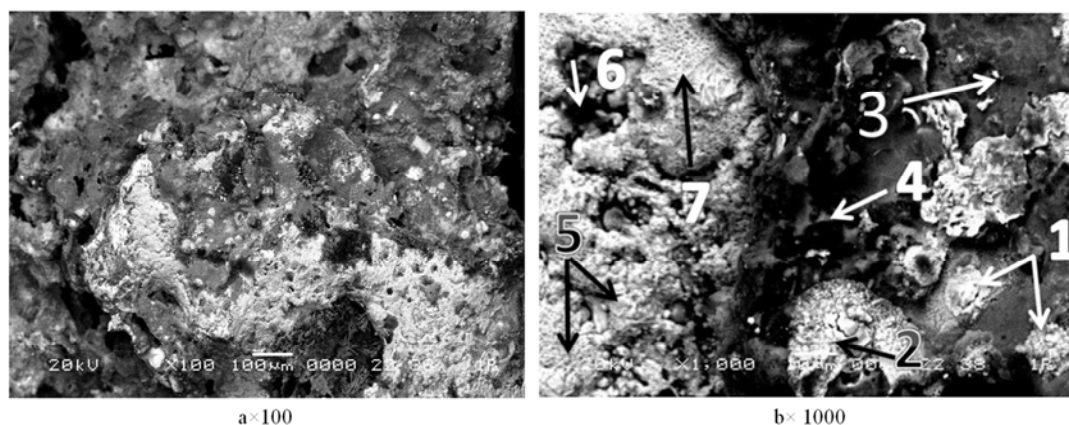


Figure 4. The slag structure during the smelting on the classic charge (investigated by scanning electron microscopy).

A significant decrease in the slag density (table 4) is explained by the high reducing ability of the polymer pyrolysis products. In all components of the initial slag, the concentration of iron is 2-3 times higher than its concentration in melts with the introduction of charge bales from scale, cement, and polymers are introduced (table 5). In this case, the dynamics of reducing concentration of metal elements (Si from 21.05% to 19.11%, Mn from 10.22% to 4.49%, Cr from 1.13% to 0.07%, Ni from 0.17% to traces, Ti

from 0.10% to traces, Al from 2.21 to 2.09%, Na from 0.43% to 0.11%, Pb from 0.22% to traces) in the slag; the volume of introduced charge is increased (Table3).

The introduction of charge materials, including scale, cement and polymer, the iron is reduced and it transfers to the cast iron (table 3).

The density of the resulting slag during the smelting of cast iron on the classic charge and using new charge materials is completely different (table 5).

Table 5. The density of the original smelting on the classic charge and using new charge materials.

Smelting conditions	smelting on the classic charge	Introduced: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	Introduced: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)
Slag density, g/cm ³	3.77	2.52	1.01

Table 6. Chemical composition of non-metallic slag inclusions after introducing bales of scale and elastomers waste (grounded tyres) into the melt.

Mass fraction of the introduced additive, % wt.	Position of Inclusion	Contents of elements, % wt											
		C	O	Si	Mn	S	P	Cr	V	Ti	Cu	Ni	Mo
Not introduced	1 (figure 4b)		24.27	1.95	1.69	0.12				0.17			
	2 (figure 4b)	6.01	23.73	4.03	1.27		0.24	0.30		0.06			
	3 (figure 4b)	4.62	41.55	28.08	4.32	0.29	0.06		0.19	0.51			
	4 (figure 4b)	39.33	22.09	12.92	0.98	0.20	0.21			0.16			
	5 (figure 4b)	4.32	21.29	0.68	16.67	0.04				0.11			
	6 (figure 4b)	0.86	24.02	2.10	2.61		0.03			0.19			
	7 (figure 4b)		23.62	1.23	1.44	0.11	0.04	0.50	0.03				
Introduced as part of charge bales: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	average (figure 5a)	6.35	31.51	13.13	10.22	0.12		1.13		0.10		0.17	
	1 (figure 5b)			38.87	9.10			0.60		0.73	0.29	0.61	
	2 (figure 5b)	4.29	27.31	7.13	10.81		0.09	0.21		0.61	0.32		
	3 (figure 5b)	6.54	27.53	8.02	2.11	0.62	0.17	0.87		0.16	0.46	5.12	0.61
	4 (figure 5b)	3.09	27.68	4.61	7.18	0.06	0.05	15.38	0.35	0.40	0.12	0.14	
	5 (figure 5b)	11.81	31.20	14.74	4.43		0.19	1.43		0.29	0.28		1.09
	6 (figure 5b)	9.43	32.55	14.87	6.10		0.12	1.92	0.13	0.11			0.89
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	average (figure 5c)	8.83	34.60	19.11	4.49		0.02	0.07	0.09				
	1 (figure 5d)	12.62	39.54	27.05	1.81	0.07	0.01	0.24	0.01	0.24			
	2 (figure 5d)	4.01	35.09	17.84	5.33		0.12	0.65		0.27		0.22	
	1 (figure 5e)		39.06	22.59	3.57								
	2 (figure 5e)	301	34.45	17.99	4.70	0.18	0.21	0.91	0.12	0.37	0.24	0.55	

Table 6. Continued.

Mass fraction of the introduced additive, % wt	Position of Inclusion	Contents of elements, % wt											
		Al	Na	Mg	K	Ca	Co	Zn	As	Sn	Pb	N	Fe
Not introduced	1 (figure 4b)	1.05		0.60		0.16					0.88		69.11
	2 (figure 4b)	1.51				0.27						3.85	58.73
	3 (figure 4b)	5.33		1.10	0.13	2.68						8.54	2.59
	4 (figure 4b)	5.04	1.12	0.14	0.73	1.28						13.08	
	5 (figure 4b)	0.25	0.07							0.03	3.18		53.36
	6 (figure 4b)	0.77		0.26	0.05	0.31							68.80
	7 (figure 4b)	0.53		0.22		0.02							72.26
Introduced as part of charge bales: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	average (figure 5a)	2.21	0.43		0.17	7.00				0.22			27.26
	1 (figure 5b)	5.90		0.14	0.12	8.14	0.21		0.79	0.21			34.29
	2 (figure 5b)	0.75		0.45	0.06	5.70		0.47		0.04			41.76
	3 (figure 5b)	0.87		0.10		1.10		0.52	0.17	0.03	0.26		44.73
	4 (figure 5b)	0.87	0.28	0.22		1.85		0.10		0.36			37.25
	5 (figure 5b)	1.77	0.44		0.06	3.56		0.50	1.17	0.36			26.67
	6 (figure 5b)	2.55	1.03	0.97	0.07	4.43							24.82
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	average (figure 5c)	2.09	0.11	0.11	0.15	6.55	0.38		0.94	0.40			21.78
	1 (figure 5d)	2.80		0.52		5.81	0.36						8.91
	2 (figure 5d)	2.12	0.34	0.30		6.02		0.24	0.54		0.09		26.84
	1 (figure 5e)	2.37				7.83							24.58
	2 (figure 5e)	2.51		0.11		6.59						6.68	21.14

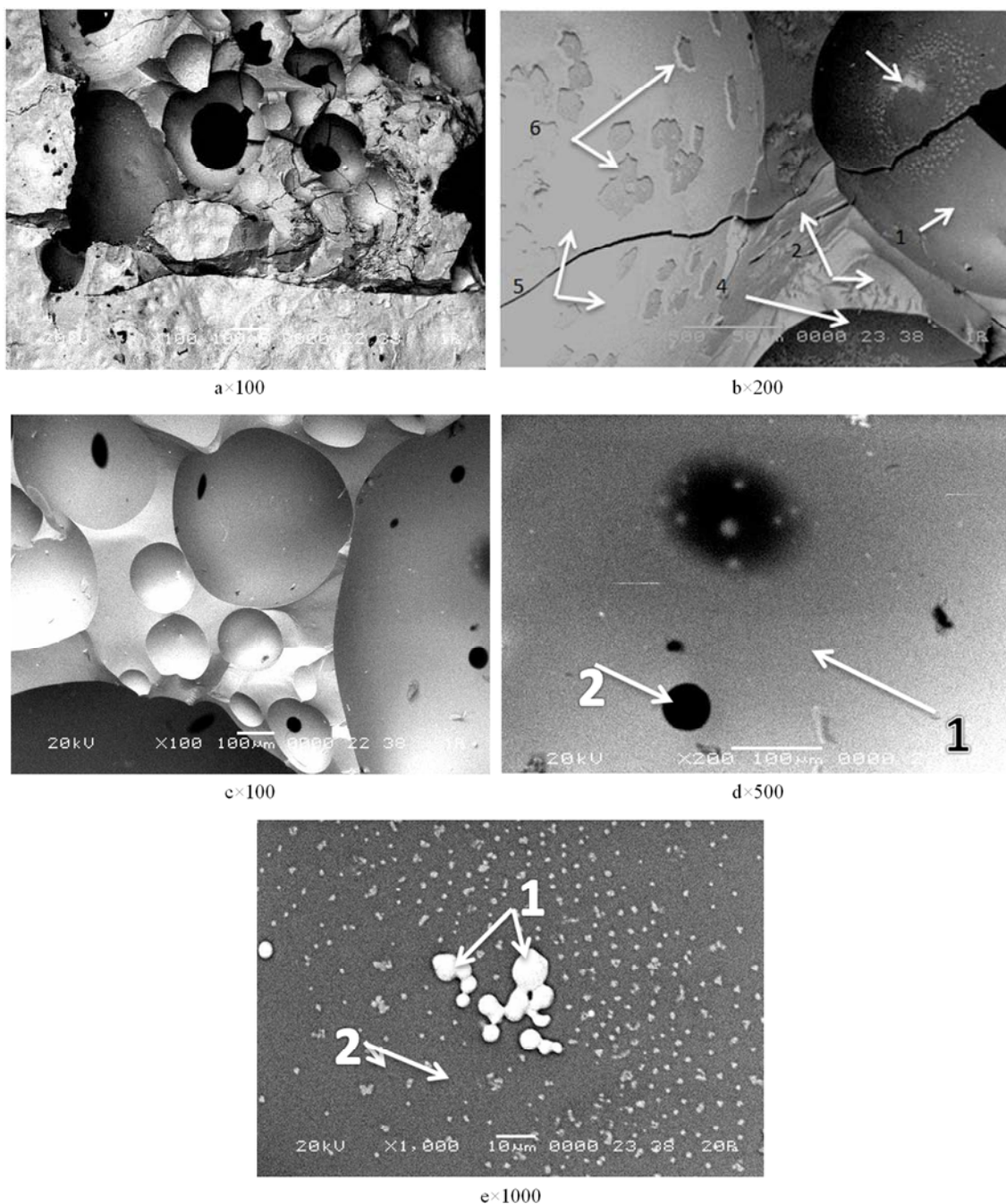


Figure 5. Slag structure (investigated by scanning electron microscopy).

a, b-introduced as part of charge bales: 7 kg scale, 1.7 kg cement, 0.35 kg rubber (pieces of tyres); c, d, e-introduced as part of charge bales: 14 kg of scale, 3.4 kg of cement, 0.75 kg of rubber (pieces of tyres).

5. Processes of Structure Formation in Cast Iron When Scale Is Used in Charge

The structure of cast iron was studied according to the national standard (GOST) 3443-87. The structure of cast iron was determined by graphite and metal base. When graphite is defined, the following parametres are assessed: shape, distribution, size and number of graphite inclusions. When the metal base is defined, the following parametres are

assessed: structure type, shape of pearlite, amount of pearlite and ferrite, dispersion of pearlite.

The study of graphite was carried out on a non-etched metallographic sample, and metal base – on the metallographic sample after etching. The following reagent was used to etch the surface sample: 4 ml HNO_3 (density 1.4 g/cm^3) and 96 ml ethyl alcohol.

To determine the structure of cast iron, the sections were examined under a microscope at the following magnifications:

1. the overall structure was increased 10 to 200 times;

2. the shape, distribution, inclusion size, and graphite amount was increased 100 times;
3. the metal base type – at 500 times magnification;
4. the amount of pearlite and ferrite – at 100 times magnification;
5. the dispersion of lamellar pearlite – at 500 times magnification.

The structure of cast iron was analyzed according to the national standard (GOST) 3443-87 and compared visually to the structure that is visible in the microscope and the structure of an appropriate scale.

When the structure formation processes after introducing the bales of iron-containing waste and polymer waste were studied, the task of finishing the metal composition to meet the requirements of technological conditions for specific castings was not set.

The study of the cast iron microstructure after introducing bales of scale and elastomers waste (grounded tyres). In the original melt (figure 6), we observe a structure (table 7) with uniformly distributed flaked graphite of rectangular shape, length approximately 60-120 microns. Metal base - lamellar pearlite about 60% (F40) with 0.5 μm interlamellar

distance. Triple fine-grained phosphide eutectic is evenly distributed, cell diameter is 400 microns, the area of eutectic inclusions is 2000 microns.

In the original melt there is a lot of ferrite, so it is difficult to isolate phosphide eutectic, but it is present in a small amount.

After introducing into the melt charge bales (7 kg scale, 1.7 kg cement, 0.35 kg rubber (pieces of tyres)), the structure of cast iron (figure 7) is close to the structure of the original melt, with a significantly increased amount of pearlite and phosphide eutectic (table 7).

Increase in the number of charge bales (14 kg scale, 3.4 kg cement, 0.75 kg rubber (pieces of tyres)) leads (figure 8) to an increase in the amount of pearlite by appr. 95%. There is a triple fine-grained phosphide eutectic with a broken grid, the area of the largest inclusion is 13000 microns² (table 7).

The nature of changes in the chemical composition of non-metallic inclusions of cast iron (table 8) after introducing the bales with iron-containing waste and waste elastomers indicates the prospects of the suggested techniques of processing industrial waste and improving the quality characteristics of alloys simultaneously.

Table 7. The results of the studies of cast iron structure with bales with introduced iron-containing waste and waste elastomers (grounded tyres) according to the national standard (GOST) 3443-87.

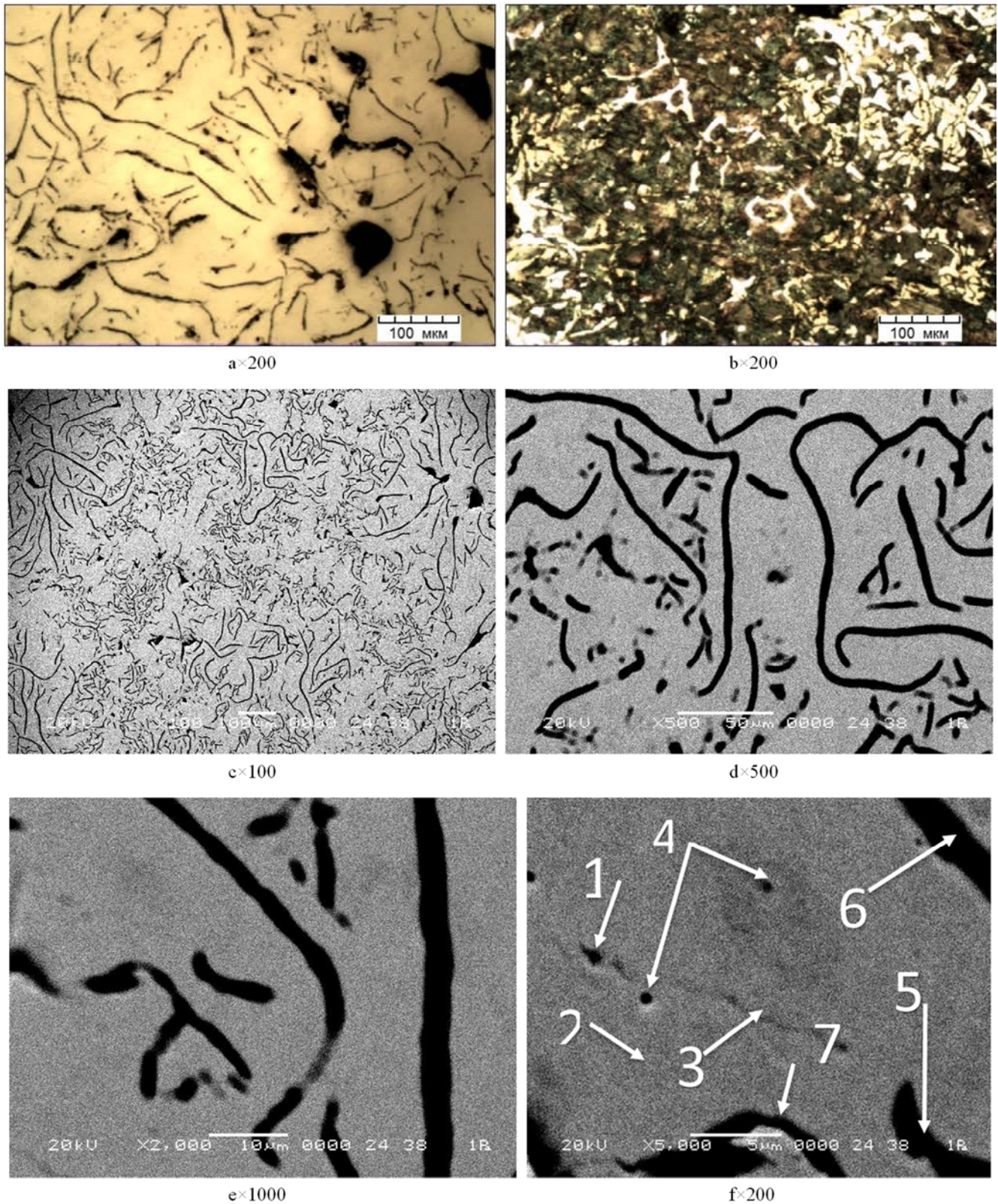
Composition of the introduced charge bales	Shape of graphite inclusions	Length of graphite inclusions	Distribution of graphite inclusions	Structure type of the metal base	Pearlite dispersion
Not introduced	Lamellar linear PGF1	PGd90	PGr1	Pt1	Pd0.5
Introduced as part of charge bales: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres).	Lamellar linear PGF1	PGd 90	PGr 1	Pt1	Pd0.5
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	Lamellar linear PGF1	PGd 90	PGr1	Pt1	Pd1.0

Table 7. Continued.

Composition of the introduced charge bales	Pearlite and ferrite amount	Phosphide eutectic inclusions structure	Phosphide eutectic inclusions distributions	Diameter of the grid element of phosphide eutectic	Phosphide eutectic inclusions area
Not introduced	P60 (F40)	Ph3	Phr1	Ph s400	Ph a2000
Introduced as part of charge bales: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres).	P90 (F10)	Ph3	Phr3	Ph s1250	Ph a2000
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	P90 (F10)	Ph3	Phr3	Ph s1250	Ph a13000

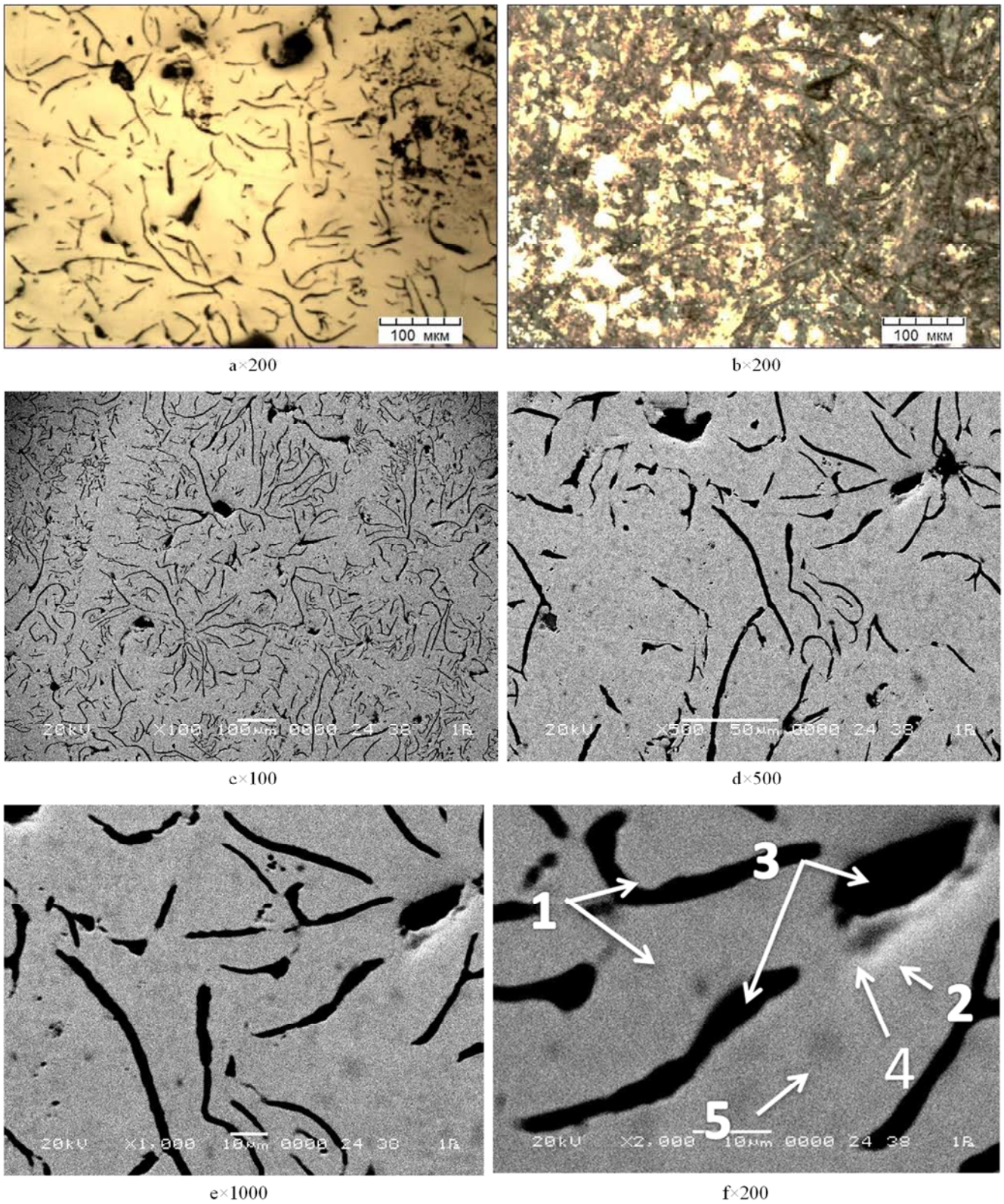
Table 8. Chemical composition of non-metallic cast iron inclusions after introducing bales with iron-containing waste and elastomers waste.

Composition of the introduced charge bales	Position of Inclusion	Contents of elements, % wt											
		C	O	Si	Mn	S	P	Cr	V	Ti	Cu	Ni	Mo
Not introduced	1 (fig. 6f)	2.85		1.39	0.35	0.09	0.36	0.28	1.03	3.43			
	2 (fig. 6f)	2.61		1.27	1.00	0.20	0.33	0.01		0.07			
	3 (fig. 6f)	1.97		1.79	0.61		0.09	0.17		0.16			
	4 (fig. 6f)	2.10		1.31	0.64		0.11	0.12		0.17			
	5 (fig. 6f)	7.21		2.42	0.13	0.08				0.14			
	6 (fig. 6f)	14.13		1.15	0.25	0.06	0.18	0.19	0.15				
	7 (fig. 6f)	20.76		0.47			0.22	0.35					
Introduced as part of charge bales: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	1 (fig. 7f)	3.01		1.46	0.61		0.23	0.25	0.06	0.05		0.28	
	2 (fig. 7f)	4.70		1.33	0.65			0.09	0.01		0.58	0.34	
	3 (fig. 7f)	26.36		1.66	0.35	0.07					0.05	0.04	0.40
	4 (fig. 7f)	2.96		1.48	0.65		0.24	0.29	0.07		0.15	0.12	
	5 (fig. 7f)	4.28		1.49	0.42							0.93	0.63
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	1 (fig. 8e)	2.69	2.81	1.25	0.30			0.14			0.97	0.24	
	2 (fig. 8e)	26.82	0.52	1.21	0.04			0.04	0.18	0.30		0.15	0.50



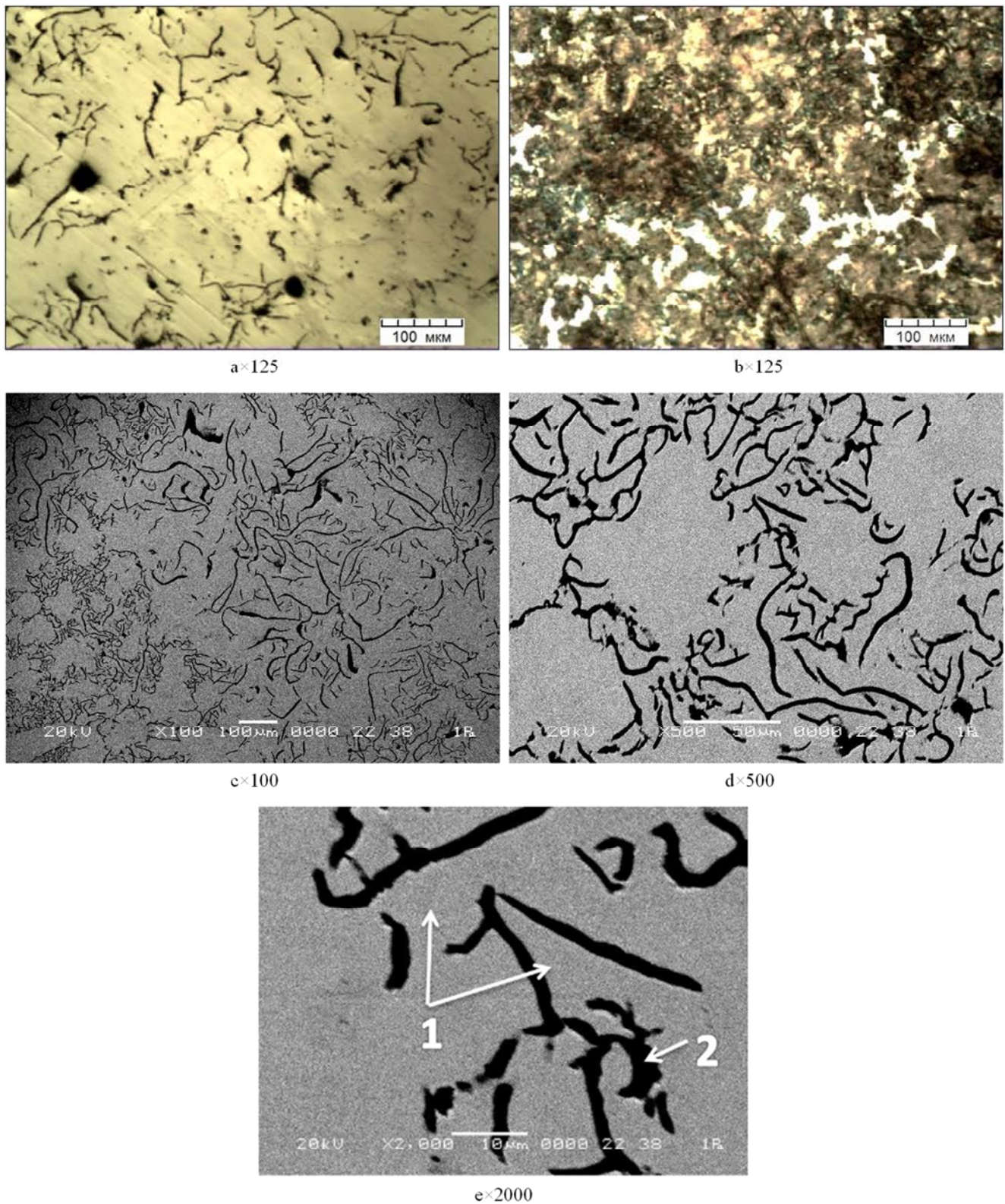
a, b-metallographic studies; b, d – investigated by scanning electron microscopy; a, c, d, e, f- non-etched; b-etched.

Figure 6. The structure of the original cast iron before introducing into charge the bales with iron-containing waste and waste elastomers (grounded tyres).



a, b-metallographic studies; c, d, e, f – investigated by scanning electron microscopy; a, c, d, e, f - non-etched; b-etched.

Figure 7. The structure of the cast iron after introducing the charge bales with iron-containing waste and waste elastomers (grounded tyres) into the melt.



a, b-metallographic studies; c, d, e – investigated by scanning electron microscopy; a, c, d, e - non-etched; b-etched.

Figure 8. The structure of cast iron after introducing charge bales: 14 kg scale, 3.4 kg cement, 0.75 kg rubber (pieces of tyres) into the melt.

Table 8. Continued.

Composition of the introduced charge bales	Position of Inclusion	Contents of elements, % wt											
		Al	Na	Mg	K	Ca	Co	Zn	As	Sn	Pb	N	Fe
Not introduced	1 (fig. 6f)											1.63	88.60
	2 (fig. 6f)												94.51
	3 (fig. 6f)												95.21
	4 (fig. 6f)											3.42	92.13
	5 (fig. 6f)											3.12	86.89
	6 (fig. 6f)											8.99	74.90
	7 (fig. 6f)											3.97	74.24
Introduced as part of charge bales: scale 7 kg, cement 1.7kg, rubber 0.35 kg (pieces of tyres)	1 (fig. 7f)					0.06					0.28	1.52	92.21
	2 (fig. 7f)	0.17		0.09							0.67	0.71	90.65
	3 (fig. 7f)			0.09	0.13				0.69	0.59		4.74	64.80
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	4 (fig. 7f)		0.23	0.08		0.12	0.33	0.54	0.71			5.42	86.60
	5 (fig. 7f)	0.13	0.15	0.04	0.40	0.06		0.02	0.35	0.35		2.81	87.94
	1 (fig. 8e)	0.03	0.54						0.49				90.54
Introduced as part of charge bales: scale 14 kg, cement 3.4kg, rubber 0.75 kg (pieces of tyres)	2 (fig. 8e)	0.02		0.26			0.39						69.58

6. Conclusion

Recognition of the leading place of science as an integral constituent of R&D focuses the attention on the problem area search for so-called pioneer (or close to in technical terms) techniques; their implementation will fundamentally change the research field of state-of-the-art science, form new vectors of its development. The characteristic features of development efficiency and innovation should cover several criteria, including the costs reduction per unit of output. Difficult situation in the market of metal charge encourage commercial and technical services of enterprises that use scrap in the casting alloys production, to search for alternative materials and technologies.

1. New charge materials and technologies (patents of the Republic of Belarus № 11641, 14183) based on breakthrough scientific developments of the Belarusian state technological University, allow us to extract metals effectively from non-traditional types of charge (iron-containing dust, sludge of cupola gases, iron-containing sludge, scale, rust, grinding sludge, cast iron and steel turnings, waste of facing materials, waste catalysts of chemical and petrochemical industry) using a new class of reducing agents (atomic carbon and hydrogen). The reprocessing technology is accompanied by pyrolysis of polymers and homolytic cleavage of bonds with hydrogen and carbon atoms (hydrocarbon radicals) formation, reducing iron from new charge materials and other metals that provide modification, including the centers formed in the melt as a result of chemical reactions.

2. The formulation and component composition of the packages was defined out. The method secures technological strength and indestructibility of bales during transportation, heating and melting. The bales can withstand 2-3 impacts without destruction when hitting a metal plate from 1.5 m height). There is no destruction of bales during heating and melting.

3. New materials and technologies created on the basis of breakthrough scientific developments of the Belarusian state technological University allow us to effectively extract metals

from unconventional charge when using a new class of reducing agents (atomic carbon and hydrogen). These agents are formed in the melt during pyrolysis of high-molecular compounds, which saves material and energy resources, reduces harmful emissions and improves the quality characteristics of alloys.

References

- [1] Harast, A. I. Iron Carbon Alloys: Structure Formation and Its Properties. Minsk, 2010.- 252p.
- [2] Konjuh, V. J. Gas-oxygen metal melting metal / V.J. Konjuh V. J. B. Я. — Kyev: Navukova dumka, 1979.— 160p.
- [3] Lekah, S. N. Alloying of cast iron from slag phase / S. N. Lekah, A. G. Sluckij, V. L. Tribushevskij //Casting production. – 1985. – Vol.10. – p. 10.
- [4] Analysis of potential trends in industrial ferrous scraps processing in the Republic of Belarus / V. I. Timoshpol'skij, M. L. German, Je. A. Stebloap et al. // Casting and Metallurgy. – 2006. – Vol. 2, part 2. – pp. 23–27.
- [5] Experience of scraps utilization. / D. M. Kukuj, I. V. Emel'janovich, V. P. Petrovskij et al. // Casting and Metallurgy. – 2009. – Vol. 1. – pp. 47–50.
- [6] Kinetics of iron alloying in slag phase / O. S. Komarov, I. B. Provorova, V. I. Volosatikov et al. // Casting and Metallurgy. – 2008. – Vol.1. – pp. 112–115.
- [7] Lekah, S. N. Oxygen activity in liquid iron and deoxidation / S. N. Lekah, D. N. Hudokormov, A. F. Vishkarev // Casting and Metallurgy. – 1986. – Vol. 3. – pp. 6–7.
- [8] Patent 116411 of the Republic of Belarus "Method of Cast Iron Smelting and Method of Steel Smelting" (2006) C 21 C 1/00, C 21 C 5/00, F 23 G 5/027 / Harast A.I. BSTU – № a20050280; appl. 24.03.2005; publ. 30.12.2006 // The Official Journal. – 2009. – № 1.
- [9] Sposob vyplavki chuguna [Method of iron smelting]: pat. 14183 Resp. Belarus: MPK (2006) C21C1/00, C21C5/00, F23G5/027 / A. I. Harast; appl. EI «Bel. gos. tehnol. un-t». – № a20091272; appl. 31.08.2009; publ. 30.04.2011 // Aficyjnybuletjen' / Nac. cjentrintjelekt. ulasnasci. [Official Bulletin. Centre of Intel. Property]. – 2010. – № 1.

- [10] Harast, A. I. Chemical Baling of Oily Cast Iron Turnings and Use of Bales to Substitute Expensive and Scarce Scrapes / A. I. Harast // International Journal of Materials Science and Applications. – 2013. – Vol. 2, No. 6. – PP. 194–203. doi: 10.11648/j.ijmsa.20130206.15.
- [11] Harast, A. I. Modification and Microalloying of Iron Carbon Alloys Using Industrial Polymer Scrapes / A. I. Harast // Journal of Current Advances in Materials Sciences Research (CAMSR). – 2014. – Vol. 1, Issue 3. – PP. 66–74. www.vkingpub.com/journal/camsr/ © American V-King Scientific Publishing.
- [12] Harast, A. I. The Casting Technologies Focused on the Use of Industrial Waste and Semiprocessed Products Related to Engineering Industries / A. I. Harast // Journal of Multidisciplinary Engineering Science and Technology (JMEST), ISSN: 3159-0040. – 2015. – Vol. 2 Issue 5. – PP. 914–918.
- [13] Harast, A. I. Extracting metals from non-traditional types of charge when implementing breakthrough foundry and metallurgy technologies / A. I. Harast // Home / SciencePG Frontiers. From Colloid and Surface Science. Mar. 6, 2017. <http://article.sciencepublishinggroup.com/html/10.11648.j.am.20160506.12.html>.
- [14] Harast, A. I. Formation Mechanism Of Wear Resisting Surface Layer On Cast Iron Moulds By Direct Surface Alloying / A. I. Harast // Journal of Multidisciplinary Engineering Science and Technology (JMEST), ISSN: 3159-0040. – 2015. – Vol. 2 Issue 9. – PP. 2591–2598.