ASPECTS REGARDING THE QUALITY OF CAST IRON PRODUCED IN S.C.FONTUR S.A. SUCEAVA

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Abstract: The authors analyze the quality of produced cast iron and molded forms from SC FONTUR SA Suceava. For this purpose samples were cast from different batches of samples, from which were made tensile specimens, samples for chemical and metallographic analysis and hardness control. Based on analysis conducted authors show corrections that have to be made to the chemical composition and of cast iron structure to obtain high mechanical strength. Also they give recommendations on improving technology development.

Keywords: *cast iron, chemical composition, microstructure, mechanical properties, moulding*

1. General aspects

Increased production of iron castings is due primarily to the fact that cast iron is the cheapest casting metallic material with great technological properties and tensile strength, that for nodular ductile cast iron is simillar to those of steel. The moulding cast iron technologies are more simple and give better reproductibility of results.

Gray cast iron structure is made of: basic metallic mass (mold) and graphite.

Basic metallic mass is simillar to hipo or eutectic steel ($C_{mb} \leq 0,77\%$). It can be:

- ferritic, carbon of metallic core mass is ≈ 0.1% C, polyhedral aspect, soft, HB = 100 ... 120;
- ferito-perlite, $C_{s0,77} > C_{mb} > C_{sol}$ made of white polyhedral ferrite grains (around graphite) and lamellar pearlite, HB = 140...180 ;
- perlite, $C_{mb} = C_{s0,77}$, with lamellar aspect, hard and resistant, HB = 250...340.

Where graphite is grossly spread , its influence on cast iron strength is prevalent, the metallic mass being insignificant, therefore primary coarse graphite cast iron have reduced mechanical strength [1].

From a structural point of view, graphite is characterized by: shape, size, quantity and distribution.

The graphite amount (occupied area) shows the filling degree of graphite formations. It depends on the total amount of carbon in cast iron composition and especially the amount of spread graphite in crystallization process. We need to consider a minimal value of graphite quantity restricted by moulding conditions. Therefore, total carbon content of gray cast iron is taken between 2.4 ... 3.8 [2],[3], [4].

With density four times lower than perlite, the actual volume occupied by graphite is much higher than the C_{gr} value (free spread graphite carbon form).

For exemple, for a cast iron with C_T=3%, that has basic perlitic mass (C_{mb}=0,77%), C_{gr}=2,23% it coresponds a volume of 9% graphite.

Shape appears to be the most important graphite classification criteria, characterized by density degree of graphite spreads, respectively the cutting degree of basic metallic mass and the tensions focusing effect. The size of graphite spreads also influences the mechanical proprieties especially lamellar graphite.

The prevalent role of graphite concerning the reduced level of cast iron mechanical characteristics derive from its negative effects, namely:

- ***cutting effect***, respectively decreasing basic mass usefull section in takeover mechanical process of solicitations;
- ***isollating effect*** of basic metallic mass portions or areas, favorizing a distribution and a unequal takeover – discontinuous of solicitations, especially in graphite interdendritic distribution in compact or discontinuous network form;
- ***focussing effect*** due to values of 10 to 100 times bigger regarding the medium value of mechanical tensions, especially in lamellar spread peaks area, causing premature rupture during tablets.

Tab.1.- Chemical composition of analized banks

No. crt.	Date 2010	Chemical composition, %														
		C	Si	Mn	Ph	S	Cr	Mo	Ni	A1	Co	Pb	Sn	Ti	V	W
1	20.04	3.79	1.75	.436	.113	.153	.119	.048	.092	.005	.236	.015	.020	.026	.017	.007
2	25.06	4.01	1.95	.447	.085	.152	.155	.048	.104	.005	.341	.013	.027	.024	.027	.007
3	31.07	3.92	1.86	.414	.102	.148	.151	.049	.101	.005	.197	.011	.021	.023	.015	.007
4	25.08	4.00	1.88	.413	.085	.126	.161	.050	.101	.005	.319	.011	.028	.022	.025	.007
5	06.09	3.86	1.88	.407	.075	.125	.146	.041	.098	.004	.203	.009	.016	.022	.015	.007
6	07.10	3.95	2.05	.428	.059	.089	.132	.041	.106	.023	.141	.010	.017	.025	.015	.007

The mechanical characteristic values indicate the total unfavorable influence of lamellar graphite with sharped peaks – with maximal cutting effect – on rupture restistence – (Rm=100...350MPa), and also on specific elongation (A<0,5%), those cast irons being considered fragile[4].

The experimental researches and current practics showed that the most resitent cast iron is the one with perlitic metallic mass, that contains the most fine and uniform spread graphite.

The most important metallurgical processes leading to increasement of mechanical resistence and tenacity of cast iron are following, by primary structure modication, the purposes given below:

a) ***graphite modification***, by:

- obtaining the most compact form;
- the most uniform distribution into metallic mould;
- dimensions decreasement of graphite spreads;
- decreasement of graphite quantity.

b) ***metallic basis modification***, by:

- crystalline refinement (grains dimension decreasement and consequently grains number increasement on volum unit);
- percentage decreasement of unmetallic phases and segregations due to grains limit.

In conclusion, for a better characterization of cast iron mechanical behaviour is necessary an interdependence analysis between structure and properties.

In this paper authors have analyzed the quality of cast irons produced by SC FONTUR SA Suceava Company, following the purpose of finding the technical solutions that would lead to the increasement of its strength.

2. Experimental researches

S.C. FONTUR Suceava S.A. Company regularly delivered banks of cast samples, according to SR EN 561 from which have been made:

- samples for chemical and microstructural analysis, and hardness control;
- samples for tensile test.

2.1 Chemical analysis

Chemical analysis has been made by S.C. EXPROTERM S.A. Suceava on a Quantovac 3460 machine.

The results of chemical analysis are given in tab.1.

In obtaining gray cast irons with lamellar graphite, with superior mechanical strength, basic elements content (C, Si, Ph, Mn, S) are chosen in a way that assures a minimal quantity of graphite in cristalization, and on the other hand, when the eutectic transformation is finished, we have to achieve a complete perlitic structure.

In cast iron characterization from chemical composition's point of view due to Fe-C binary diagram are beeing used two notions: equivalent carbon and eutectic degree of saturation. Those are measures that allow position determination of a cast iron given in relation to Fe-C eutectic.

The most common formula in equivalent carbon determination is [5]:

$$C_{ech} = C_t + 0,3\ (Si + P)$$

where Ct is total carbon from cast iron (chemical determinated). Cech of cast iron fixes its position due to stabile eutectic (4,26%) or metastabile (4,30%) of Fe-C alloys.

Eutectic saturation degree SC is another way to put a given cast iron in relation to Fe-c eutectic in silicon and phosphorus presence, the eutectic saturation degree being equal to 1. Saturation degree can be determined with one of the following formulas:

Tab.2.- Maximal saturation value and of K characteristic in carbon

No.crt.	$C_{echiv..}$	$C_{eut.}$	$C'_{eut.}$	C_S	C'_S	K
1	4,428	3,641	3,681	0,398	0,516	0,812
2	4,707	4,035	4,075	0,366	0,486	0,940
3	4,583	3,920	3,960	0,379	0,499	0,883
4	4,665	3,334	3,374	0,375	0,495	0,902
5	4,513	3,206	3,243	0,376	0,496	0,886
6	4,628	3,271	3,311	0,351	0,471	0,985

$$S_C = \frac{C_t - C_E}{C_C - C_E} \text{ or}$$

$$S_C = \frac{C_t}{C_C} = \frac{C_t}{4{,}26 - 0{,}3(Si + P)}$$

where CC =4,26-0,3 (Si + P) is eutectic carbon content.

The equivalent carbon, eutectic carbon and the eutectoid one are calculated with relations given below:

The equivalent carbon:

$C_{echiv.}$ = C + 0,3(Si + P) – 0,03 Mn + 0,4 S + 0,07Ni + 0,05Cr + 0,074Cu + 0,25Al

The eutectic carbon:

Ceut. = 4,26 - 0,3(Si + P) + 0,03 Mn - 0,4 S - 0,07Ni - 0,05Cr

C'eut. = 4,30 - 0,3(Si + P) + 0,03 Mn - 0,4 S - 0,07Ni - 0,05Cr

The eutectoid carbon:

C_s = 0,68 – 0,15Si – 0,05(Ni + Cr + Mn – 1,7S)

$C_{s'}$ = 0,80 – 0,15Si – 0,05(Ni + Cr + Mn – 1,7S)

Saturation degree in carbon :

S_c = C / [4,26 - 0,3(Si + P)]

Cast iron structure moulded in samples with different diameters is determined into the diagram by knowing the limits of structural domaines due to K characteristic and by sample diameter, shown in tab.3.

This constant is given by formula:

$$K = \frac{3}{4} Si\left(1 - \frac{5}{3C + Si}\right)$$

Examining the determinated values for carbon content results that those are bigger than recomended to cast irons Fc200 şi Fc250:

- sulfur and phosphorus contents are above maximal limits normally recomended by standards,
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-

most of it due to usement of waste from cast iron radiators as raw material, in which content is allowed more phosphorus to increase liquid cast iron fluidity;

- equivalent cast iron carbon is above 4,26%, which leads to primary and coarse graphite appearance, and consequently to decresement of mechanical strength and cast iron tenacity.

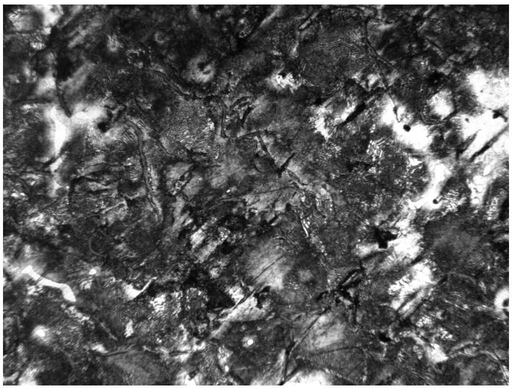
- calculated K constant is between limits 0,85...2,05, which coresponds to perlitic cast iron, fact that results of metalographic analysis of analyzed cast iron structure.

2.2 Metalographic analysis

From each bank have been made metalographic samples with Φ20x25mm that had been polished, glossed and chemical attacked with nital.

2.2.1 Bank 20.04.2010

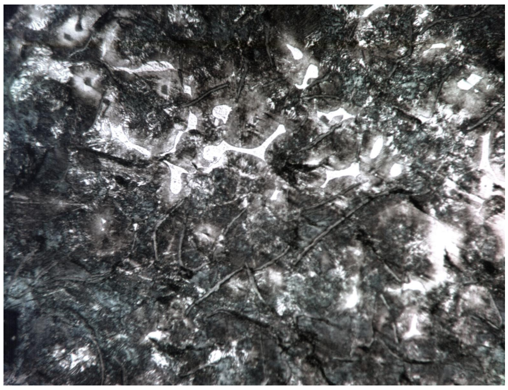
a– no chemical attack



b– attack with nital 4%.

Fig.1.- Sample microstructure of bank 20.04 2010

Cast iron structure: P + F + G; where P – perlite; F – ferrite; G – graphite.



b – attack with nital 4%.

Fig.2.- Sample microstructure of bank 25.06 2010

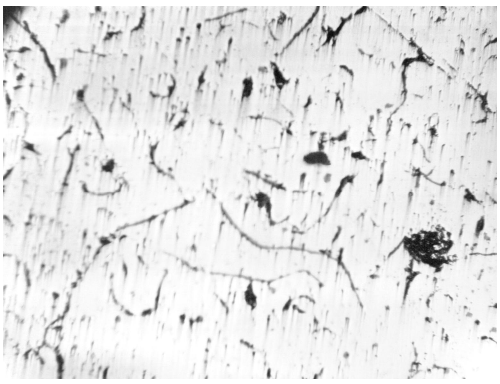
Cast iron structure: P + F + EP + G; where P – perlite; F – ferrite; EP- phosphorous eutectic; G – graphite.

Tab.3.- K for different structural domaines

Sample diameter, mm	K_a motley	K perlitic	K_b perlito-ferritic
30	0,65-0,85	**0,85-2,05**	2,05-3,10
20	0,75-1,10	1,10-2,25	2,25-3,40
10	1,05-1,50	1,50-2,35	2,35-3,50

Microstructure shown in fig.1.a presents lamellar graphite as forms of isolated separations in metallic mold.

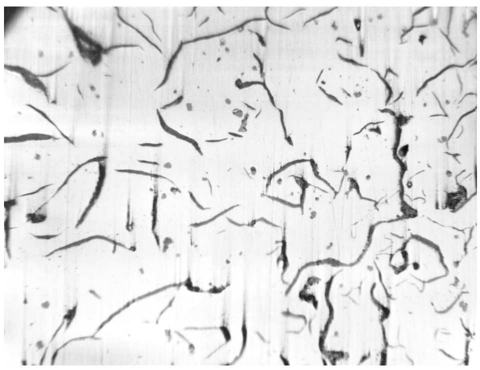
2.2.2 Bank 25.06.2010



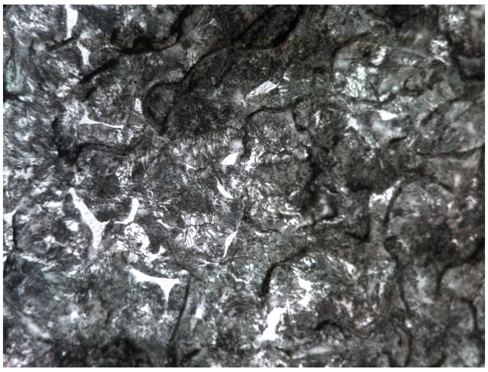
a – no chemical attack;

Microstructure shown in fig.2.a presents lamellar graphite as forms of isolated separations associated with punctiform graphite, in light coloured metallic mold.

2.2.3 Bank 31.07.2010



a – no chemical attack;



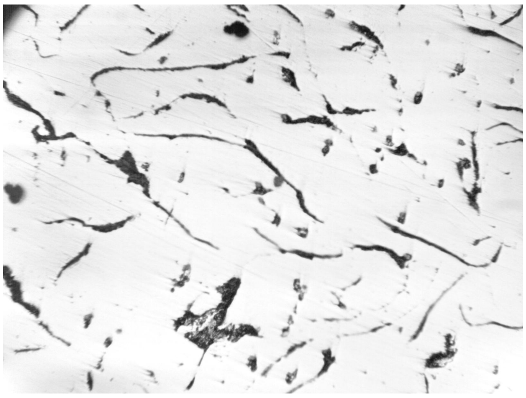
b – attack with nital 4%.
Fig.3.- Sample microstructure of bank 31.07 2010

Cast iron structure: P + F + EP + G

Where P – perlite; F – ferrite; EP- phosphorous eutectic; G – graphite.

Microstructure shown in fig.3.a presents lamellar graphite as forms of isolated separations associated with punctiform graphite, in light coloured metallic mold. Graphite arched and semiarched. Microstructure shown in fig.3.b contains: perlite (dark colour), 94,26%; ferite (light colour), under 2%; phosphorous eutectic – shiny white coloured grains, very well shaped; lamellar and punctiform graphite.

2.2.4 Bank 25.08.2010



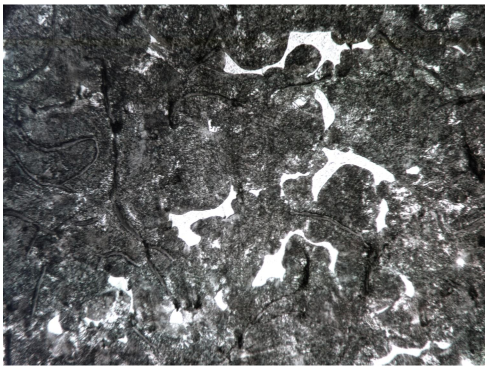
a – no chemical attack

Cast iron structure: P + EP + G

Microstructure shown in fig.4.a presents prevalant lamellar graphite as forms of isolated separations associated with punctiform graphite, in light coloured metallic mold.

2.2.5 Bank 06.09.2010

a – no chemical attack;



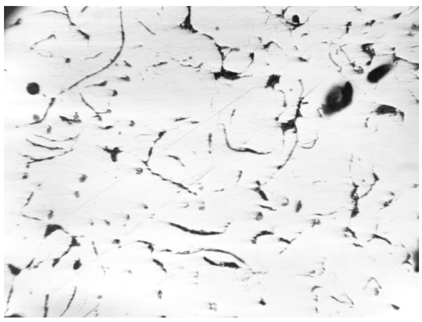
b – attack with nital 4%.
Fig.5.- Sample microstructure of bank **06.09.2010**

Cast iron structura: P + EP + G

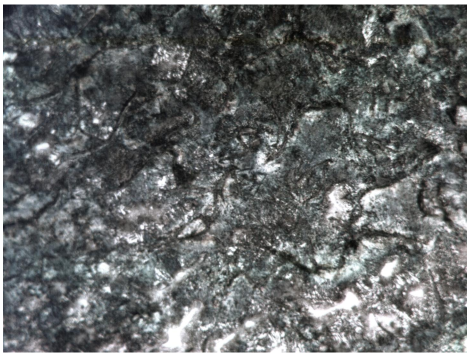
Where P – perlite; EP- phosphorous eutectic; G – graphite.

Microstructure shown in fig.5.a presents prevalant lamellar graphite as forms of isolated separations associated with punctiform graphite, in light coloured metallic mold.

2.2.6 Bank 07.10.2010



a – no chemical attack;



b – attack with nital 4%.
Fig.6.- Sample microstructure of bank **07.10.2010**

Tensile samples diameter, after chip removing process: **20 mm**, as standard SR EN 561.

Hardness samples – same prepared in metalography.

Mechanical test results are given in tab.5.

Tensile tests were done as standards SR EN 561. on processed samples with Ø 20 mm.

Hardness has been measured universal harness testing machine CV-700 with ball penetrator of 2,5 mm, downforce 1839 N, F/D^2=30, where D is ball diameter.

Tensile and harness test results are given in tab.5.

Cast iron structure: P + F + G

Microstructure shown in fig.6.a presents prevalant lamellar graphite as forms of isolated separations associated with punctiform graphite and annealing graphite, in light coloured metallic mold.

In quantity determination of graphite, perlite, ferrite and phosphorous eutectic, were used microstructures captured with OPTIKA digital camera of Science and Material Engineering Laboratory, of which overlapped measurement grids transposed by camera program. The quantity of each constituent has been determined by points method:

$$Q_{constituent} = \frac{N_c}{N_t} \cdot 100 \qquad (\%)$$

where: N_c – number of points (nodes or intersections) that fall into determined inner constituent; N_t – total network number of nodes or intersections.

Quantities of each constituent, for cast iron samples of each analized bank are given in tab. 4.

Tab.4.- Experimental determined values on constituents quantities of analyzed cast iron structure

No. crt.	**Date/2010**	**Structural constituents quantities, %**			
		Q_F	Q_P	Q_G	Q_E
1	20.04	4,72	90,59	4,69	-
2	25.06	2,34	92,70	3,03	1,93
3	31.07	-	94,26	3,92	1,82
4	25.08	-	93,76	4,12	2,12
5	06.09	4,40	91,24	4,36	-
6	07.10	4,72	90,79	3,40	1,09

2.3 Mecanical tests – tensile and hardness

Of each given sample bank had been made:

- tensile samples with calibrated part diameter of 20mm, calibrated part length of 100mm.
- samples for hardness determination, same used in metallography.

Tensile test was made on universal machine of FIMMM mechanical testing laboratory, University Ştefan cel Mare, din Suceava.

Number of samples : **at least 3 of each bank .**

Gross molded samples diameter: **30 mm.**

Based on numerous determinations it could be established several correlations between saturation degree, tensile strength and cast iron hardness:

$$\sigma_{r_{30}} = 122 - 139 S_C + 36{,}9 S_C^{-2}$$

$$\sigma_{r_{30}} = 102 - 82{,}5 S_C \quad \text{or}$$

$$\sigma_{r_{30}} = 100{,}6 - 80 S_C$$

$$HB_{30} = 538 - 355\ S_C \quad \text{or}$$

$$HB_{30} = 465 - 270\ S_C$$

where $\sigma_{r_{30}}$ şi HB30 are respectively tensile test strength and Brinell hardness on standard rods with diameter of 30 mm.

On this aspect, Namur [6] proposed as quality

Tab.5.- Tensile and hardness test results

No. crt.		Tensile				Brinell hardness, daN/mm^2			Cast iron brand as standard SR EN 561
		Sample diameter, mm	Breaking strength, (N)	**Rm, (MPa)**	**Strength's medium value, (MPa)**	Mesured values	Samples' medium value	Burden yield's medium value	
1	1	20	68452	**218**	**216,66**	199 ;192 ;211	200,6	201,9	FGL200
	2	20	70336	**224**		206 ;210 ;212	209,3		
	3	20	65312	**208**		194 ;198 ;196	196,0		
2	1	20	76105	**242.37**	**231,42**	248; 244, 252	248	248	FGL250
	2	20	68314	**217,56**		246; 244, 254	248		
	3	20	73650	**234.35**		240; 256, 252	249		
3	1	20	60393	**192.33**	**203,27**	204 ;202 ;211	205	203	FGL200
	2	20	50882	**159.49**		206 ;210 ;212	209		
	3	20	81015	**258.00**		194 ;198 ;196	196		
4	1	20	76105	**242.37**	**242.37**	287 ; 308,297	297	254	FGL250
	2	20	79542	**253.31**		248 ;234 ;241	241		
	3	20	84877	**270,31**		214 ;234 ;224	224		
5	1	20	60882	**193,89**	**206,80**	300;356 ;328	328	256,6	FGL200
	2	20	70704	**225.17**		246 ;249 ;247	247,5		
	3	20	63224	**201,35**		187 ;202 ;194	194,5		
6	1	20	79542	**253.31**	**237,10**	287 ;308 ;297	297	254	FGL250
	2	20	75400	**240,12**		248 ;234 ;241	241		
	3	20	68450	**217,89**		214 ;234;224	224		

apreciation cast iron criteria the mechanical massiveness invariant:

$$i = \frac{\sigma_r^{\ 2}}{HB^3}[mm^2 / kg].$$

That is characteristic to a chosen cast iron, because it does not depend on sample dimension onto which is being measured of (on condition that σr şi HB have to be measured on the same sample).

The following paragraphs presents tipical values for i (in µm2/kg, that eliminates 10-6):

- cast irons for stoves with 1-1,5% P i=20-40;
- semiphosphorous cast irons (0,5-0,9% P) i= 35-50 ;
- unmodified hipoeutectic hematite cast iron i=50-75;
- hematitical cast irons modified with 0,1-0,2% SiCa i=65-90;
- perlitic mechanic cast iron i=80-110;
- cast irons with 0,25% Ti şi 0,25% V modified i= 90-120;
- soft steel i=l100-1300.

At the same saturation degree, tensile test strength can vary into a wide domain and it

allowed to Patterson [7] to propose a new criteria of quality cast iron apreciation namely **relative strength RR** or **ripe degree (Reifegrad):**

$$RR = \frac{\sigma_r}{102 - 82{,}5S_C} \quad \text{or}$$

$$RR = \frac{\sigma_r}{100{,}6 - 80S_C},$$

where counter (σr) represents determined test strength of chosen cast iron, and denominator represents theoretical strength. Quality index shows the increasement or decreasement of given cast iron strength due to calculated medium value.

Variation limits of relative strength are between 0,6-1,3 and in vacuum overheated cast irons, this may decrease up to 0,4. In the same way we can define another index, called **relative hardness, RH**:

$$RH = \frac{HB}{538 - 355S_C} \quad \text{or}$$

$$RH = \frac{HB}{465 - 270S_C},$$

that shows how much given cast iron hardness varies due to medium value, theoretically calculated as on formula .

Combining the ecuations we can determine **relative hardness** due to strength:

$$RH = \frac{HB}{100 + 4{,}3\sigma_r} \quad \text{or}$$

$$RH = \frac{HB}{125 + 3{,}4\sigma_r}.$$

Value of RH can vary between 0,8-1,3 and decreases by modification. Cast iron overheated with lower RH, leads to its increasement.

Because lower hardness of a given strength is an index of cast iron superior quality (greater plasticity and tenacity, better processability), **general cast iron quality index (IC)** is the relation between relative values of cast iron hardness and strength, for example:

material in processing waste from cast iron radiators, being admitted in their contents more phosphorus to increase liquid cast iron fluidity;

- cast iron equivalent carbon is above 4,26%, that leads to primary and coarse graphite appearance and consequently to a decreasement of mechanical cast iron strength and tenacity.
- calculated K constant is between limits o,85...2,05, that corresponds to a perlitic cast iron, fact resulted from metalographic analysis of analized cast iron structure.
- analyzed cast iron structure is mostly perlitic, ferritic content being reduced. This structure offers good mechanical strength to processed cast irons.

$$IC = \frac{RR}{RH} = \frac{\sigma_r}{HB} \cdot \frac{538 - 355S_C}{102 - 82{,}5S_C}.$$

Cast iron quality is improved as relative strength value increases and relative hardness decreases.

By knowing different technological parameters (chemical composition, eutectic cell number, relative thickness of wall piece) we have to determine major mechanical characteristics based on different empiric formulas established by processing numerous tests (tab.6).

Tab.6.- Mechanical characteristics calculation of cast iron with lamellar graphite (Fgl) based on simplified relations[8]:

The characteristic	Measurement unities	Calculation relation	Observations
Flowing limit, $R_{p0,2}$	MPa	$\mathbf{R_{p0,2} = (0{,}75\text{-}0{,}85)R_m}$	R_m – breakage strength, Mpa
Tensile breakage strength on rods of Ø30, R_{m30}	MPa	$\mathbf{R_{m30} = 122 - 139\, S_c + 36{,}9\, S_c^{-1}}$	S_c – saturation degree in carbon $S_c = \frac{C}{4{,}26 - 0{,}3(Si + P)}$
Idem, R_{m30}	MPa	$\mathbf{R_{m30} = 102 - 82{,}5\, S_c}$	
Idem, R_{m30}	MPa	$\mathbf{R_{m30} = 100{,}6 - 80\, S_c}$	
Hardness HB_{30}	MPa	$\mathbf{HB_{30} = 538 - 355\, S_c}$	Idem
Idem HB_{30}	MPa	$\mathbf{HB_{30} = 465 - 270\, S_c}$	
Tensile strength on a sample or on a piece with unknown diameter (Ø=X, R_{mX})	MPa	$\mathbf{R_{mX} = R_{m30}\, (HB_X / HB_{30})^{3/2}}$	R_{m30}, HB_{30} – known for samples Ø30; also, R_{mX} known for sample Ø=X.
Tensile strength, R_m	MPa	$\mathbf{R_m = 7(13{,}5 - 2CE - 2{,}3 \log g)}$	CE – equivalent carbon, %; G – wall piece thickness, mm

2.4 Conclusions

From chemical composition analysis results following conclusions:

- carbon content is higher than recomended for cast irons Fc200 şi Fc250;
- sulfur and phosphorus contents are above maximal limits recomended by standard procedures, most of it due to usement as raw
- Graphite has lamellar shape and its distribution as form of isolated separations; some samples also have punctiform and annealing graphite;
- Banks 2, 3, 4 şi 5 – have phosporous eutectic in their structure, constituent that weaken cast irons, reducing their mechanical strength to shocks.

By determined strength, cast irons of processed banks fit into standardized brands :

- **FGL 200 (Fc200) – banks 1 ; 3 şi 5 ;**
- **FGL 250 (Fc250) – banks 4 şi 6.**

Recommendations:

- processing temperature increasement in cupola ;
- use of air enriched with oxygen in processing;
- supplementary desulphurisation and dephosphorusation;
- changing processing aggregate, purchasing an induction furnace for processing that will assure superior qualities of processed cast irons and the posibility of modifying those.

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