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Wear resistance of chromium cast iron – research and application

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Properties

ABSTRACT

Purpose: A short characteristic of wear resistance chromium cast iron has been presented as well as possibilities of this material researches realization in Foundry Department have been discussed.

Design/methodology/approach: Main attention was given on research process of crystallization and analysis of chromium cast iron microstructure and its resistance on erosion wears. Separate part of paper was devoted to discuss the bimetallic castings with chromium cast iron layer as well as typical applications of chromium cast iron castings in minig, proccesing, metallurgical and power industry.

Findings: The new method of crystallization process research with three testers (DTA-K3) was found in the work. The method makes possible to characterize sensitivity of chromium cast iron on cooling kinetic.

Research limitations/implications: DTA-K3 method can be used for research of crystallization proccess of cast materials particularly for abrasion-resisting alloy.

Practical implications: Wide scope researches of chromium cast iron in Foundry Department enable extending applications its material in many industries.

Originality/value: Value of the paper is the presentation of researches possibilities which undertaken in Foundry Department within the range of wear resistant materials.

Keywords: Wear resistance; Metallic alloys; Casting; Chromium cast iron; Crystallization; Application

1. Introduction

Abrasive wear (abrasive-percussive) of materials is fundamentally technical and economic important [1,2]. Wear is cause of huge losses. Variety of abrasive wears processes leads to material specialization in aim of assurance as good as possible resistance on wear in specific conditions. At present state of knowledge theoretical expectation of abrasive wear value in different tribologic systems is not possible because processes occur in them are very complicated [3]. From among different types of abrasive, the biggest loss causes abrasive with mineral materials i.e. silica sand, granite, metal ores and coal. It results from different reason, among other things high hardness of this materials, sharp edge of particles and often its percussive effects. Abrasion and surfacing fatigue have a crucial influent on size of abrasive wear of working element in working element – mineral system.

Among Fe alloys chromium cast irons are specific group of materials, which characterize themselves very high resistance on such type of abrasive wear. Chromium cast iron is material which chemical composition is relatively wide, 2 – 4% C and 1,5 to ca. 30% Cr in whole range it is white cast iron. Besides chromium it usually include other alloy additions from which the most important are: Mo to 3% and Ni to 5%. Moreover its cast iron may include not large amount: Cu, V, Ti, W, B and N. Taking into account different combination of chemical composition its initial microstructure is usually made up of matrix and carbides, which type mainly depends on chromium and carbon ratio. In practice principles of materials selection are function of many parameters, among other: static and dynamic load, workability, weldability, cost of production etc. Mainly technical problem, which causes limitation of application chromium cast irons on elements working in percussive condition, is relatively low crack resistance theses types of cast irons. Mechanics of brittle materials wear is connected with its susceptibility to brittle fracture. Stress intensity indicator K_{IC}, also called resistant on fracture, expresses quantitative depiction of this susceptibility. In spite of chromium cast iron's disadvantages they find wide application as casting material resistant on abrasion. Many countries in norms cover these cast irons in group of materials with very high abrasive wear resistance. How to decrease abrasive wear (abrasive-percussive) chromium cast iron in non-typical systems: working element – mineral? Degree of abrasive-percussive wear depend from one side on they susceptibility on abrasion other side on easily fracture nucleation and its propagation. Thus in practice there is contradiction. In general hard materials are resistant on abrasion these materials are, in the same time, not resistant on impacts. Most profitable solution of this problem seems to be use high hardness and plasticity materials, structure-heterogeneous materials Structure of materials resistant on abrasive-percussive wear should be consist of hard phase placed in ductile matrix. Hardness of hard phase should be higher than abrasion medium and resistant on fraction should be as well as possible high. From literature study and practice follows that in chromium cast iron over right chemical composition and producing technology may be get different microstructure what cause increasing usefulness for working in abrasive or even abrasive-percussive condition. It seams that mainly problem limited wide application of this cast iron in abrasive-percussive conditions is stereology of carbide phase, which determine crack resistance of cast iron. Two contradictory properties of chromium cast iron i.e. hardness and ductility may be reconciled by refinement and uniformly distribution of carbides phase in austenitic or its transformation products matrix. Microstructure shaping especially carbides phase in chromium cast iron occur mainly during crystallization of casting process.

First and probably most important condition is assurance the primary crystallization of chromium cast iron as hypoeutectic or eutectic alloy. Thanks to such attitude we avoid the crystallization of big, especially disadvantageous, and brittle hypereutectic carbides. Second also important condition is assurance crystallization of most advantage carbides type M_7C_3 in eutectic and hypoeutectic cast irons that are characterized by good morphology and good mechanical properties (hardness and fracture resistant). The next step has to be searching a way of reducing size of grain and uniformly distributing carbide phase in matrix.

2. Chromium cast iron crystallization research

Crystallization of casting alloy processes, on Foundry Department, has been researched with DTA method (Derivative and Thermal Aanalysis), which was constantly developed and improved by professor S. Jura. DTA method is at length described in paper [4]. It has been also used to evaluation of chromium cast iron quality in range of chemical composition and for determination eutectic carbon equivalent CE. Moreover the work on description of crystallization kinetic and determination of crystallization function for each phase has been taken up for chromium cast iron [5]. In Fig. 1 DTA graph of chromium cast iron with characteristic points marked has been presented, base on these points DTA parameters are read which make possible to calculate basis on worked in advance algorithm such values as: contents of carbon, chromium, silicon, carbon equivalent, hardness etc.

a)

b)

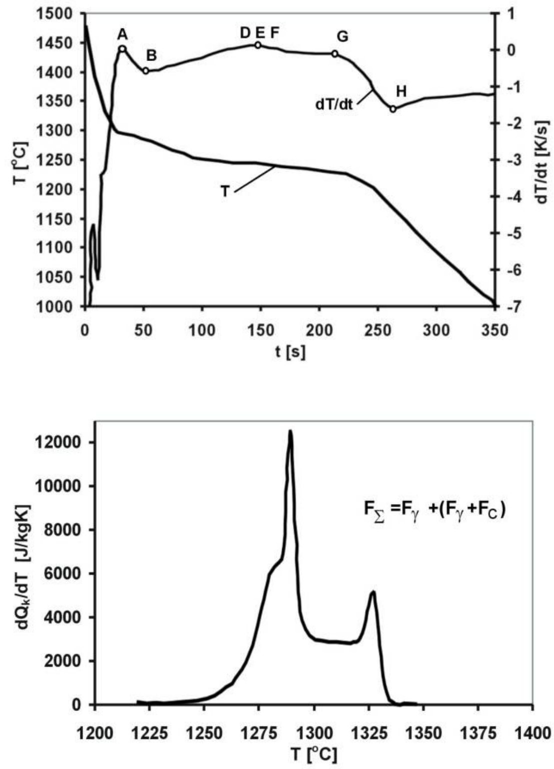

Fig. 1. a) DTA graph of chromium cast iron with characteristic point marked, b) total function of crystallization heat determined basis on DTA graph [5]

With this method can be described crystallization process only for equal dimension castings. But casting alloy in depends on casting geometry and type of mould and cast technology gets different utilitarian properties. This fact must be taking account in physical modeling. Thus a series of three testers, cylindrical shaped, different diameter, selected to more diverse kinetic of casting cooling (different castings modulus) have been constructed. For selecting geometric features of testers computer simulation has been used. For minimization of model casting and model mould dimensions the heat-insulating material have been used. In conducted tests heat-insulating with trade name SIBRAL 300 was used. Finally following diameters *d* of testers have been assumed ϕ30 mm, ϕ60 mm, and ϕ100 mm as well as the high of testers 1.5*d*. In the Fig. 2 the biggest tester with thermal insulation and in Fig. 3 scheme of whole research stand are presented. The new method of crystallization process research with three testers has been called DTA – K3. In Fig. 4 typical cooling curves for chromium cast iron and sand mould. The DTA – K3 method makes possible to characterize a sensitivity of chromium cast iron on cooling kinetic. In real castings alloys cool in non-equilibrium conditions. Model castings in DTA – K3 method also alloys cool in condition different from equilibrium. Its influence on crystallization parameters such as: characteristics transformation temperatures and intensity transformation. In Table 1 some crystallization parameters of chromium cast iron have been presented, it could be seen how they differ from each other in dependence on casting modulo.

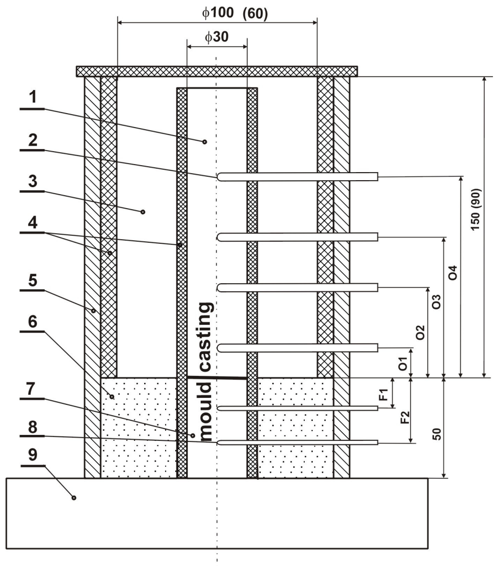

Fig. 2. Construction of tester with thermal insulation 1 – model casting ϕ30 mm 2 – quartz protector of thermocouple in casting, 3 – thermal insulator, 4 – insulation material, 5 – steel pipe, 6 – mould insert, 7 – model mould ϕ30 mm, 8 – quartz protector of thermocouple in mould, 9 – base, O1, O2, O3, O4 – distance of thermocouple in casting from model casting front, F1, F2 – distance of thermocouple in mould from model casting front

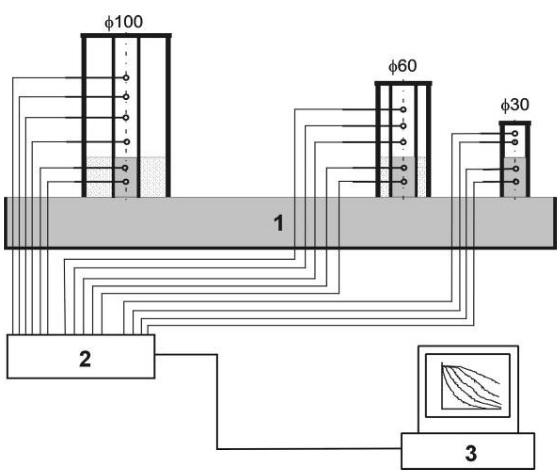

Fig. 3. Research stand scheme in DTA – K3 method, 1 – set of testers, 2 – multi-channel converter A/C, 3 – PC

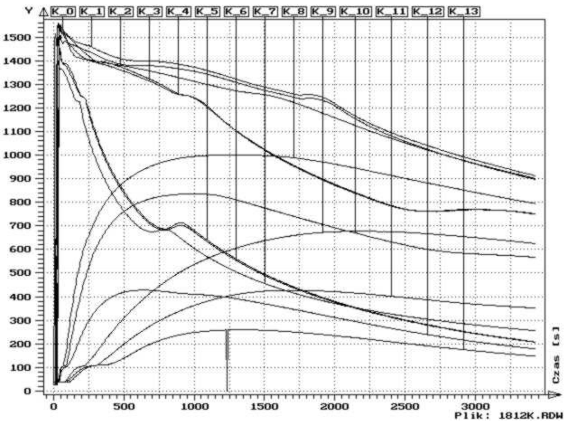

Fig. 4. Cooling curves recorded in ϕ30, ϕ60, ϕ100 mm testers (cast iron C=1.75%; Cr=11.65%)

3. Microstructure of chromium cast iron description

The aim of microstructure of chromium cast iron research is determination influence of chemical composition, crystallization process and thermal treatment on morphology and quantitative description of carbides in diverse matrix (α, γ) these cast irons. These materials contented different amount of basic elements such chromium from 6 to 24% and carbon from 1.6 to 3.2%, besides contented or not other alloy additions such as carbide-forming elements Mn, Mo, V, Ti, or else non-metal as B. Melts were carried in inductive furnace 30kg capacity. Specimens for structural researches were cast in shell mould (specimens for erosion wear research at dimensions 7x15x120 mm) or were cut off from model castings ϕ30 mm (tester of DTA – K3 method). Researches of chromium cast iron microstructure were usually conducted in as-cast condition and after austenitization in temperatures 900 and 1000^{o}C. Microsections were made in traditional way. However etching was carried out with very strong reagent for phase contrast of structure increasing what made the computer analysis of structure easier. Quantitative analysis of structure was carried out using computer picture analyzer MAGISCAN 2AR and metallographic microscope OPTIPHOT. Carbides appeared on 8-10 measurement areas are put to quantitative analysis, dedicated area – A, circumference – O, length – L, width – B of every objects are recorded, next averages and volume fraction of carbides Vv are calculated. Basis on this a histograms – graphs describing distribution of carbides amount **Na** [1/mm^2] and volume fraction **Vv** [%] in class of area (A) size are constructed. In aim of functional description of discussed parameters, empirical distributions have been approximated with special function [6]:

$$Na(A) = \frac{U_N Z_N \exp(Z_N (W_N - \ln A))}{(1 + \exp(Z_N (W_N - \ln A)))^2} \qquad (1)$$

Table 1.
Some crystallization parameters of selected chromium cast iron

Tester size	TZ	TL	TS	TH	TP	V_{ZL}	V_{ZS}	V_{LS}	V_{HP}	KH	tH	tP
	°C					°C/s					s	
C=1.75% Cr=11.65%												
ϕ100	1546	1400	1254	1207	776	0.26	0.17	0.13	0.15	0.40	2031	4895
ϕ60	1559	1394	1254	1201	763	0.55	0.34	0.23	0.26	0.66	1106	2801
ϕ30	1510	1386	1249	1199	705	2.34	1.51	1.14	0.79	2.22	243	866
C=2.25% Cr=11.37%												
ϕ100	1464	1366	1249	1199	784	0.19	0.12	0.09	0.14	0.38	2226	5223
ϕ60	1448	1355	1242	1162	766	0.43	0.27	0.21	0.25	0.49	1099	2698
ϕ30	1416	1345	1232	1186	747	1.58	0.97	0.78	0.81	1.80	289	829
C=2.92% Cr=10.79%												
ϕ100	1450	1308	1229	1150	788	0.21	0.12	0.06	0.11	0.31	2722	5972
ϕ60	1453	1300	1222	1102	782	0.53	0.29	0.16	0.24	0.44	1214	2575
ϕ30	1401	1294	1220	1148	777	1.98	1.01	0.59	0.72	1.89	344	861

TZ, TL, TS,TH, TP – temperatures: pouring, liquidus, solidus, end of crystallization, eutectoid transformation;
V_{ZL} ,V_{ZS} ,V_{LS} ,V_{HP} – the average cooling rate in corresponding range of temperature;
KH – cooling rate in the end of crystallization; tH – time of the end of crystallization;
tP – time of eutectoid transformation

$$Vv(A)=\frac{U_V Z_V \exp(Z_V(W_V-\ln A))}{(1+\exp(Z_V(W_V-\ln A)))^2} \tag{2}$$

where:
A – carbide area [μm²];
U_N, U_V – summary carbides amount factor [1/mm²], summary volume fraction [%] accordingly;
Z_N, Z_V – carbides size area diversification factor (while Z increase curves going "slender");
W_N, W_V – average logarithmic carbides size area [μm²]

For each analyzed specimen (structure) the set of parameters U, W, Z was calculated. These parameters describe in quantitative way carbide phase and are easy to further analysis. Picture of function of amount carbides distribution Na(A) and volume fraction Vv(A) in depend on state as cast or austenitized for selected melt are presented in Fig. 5 and 6 (function's parameters are presented in Table 2).

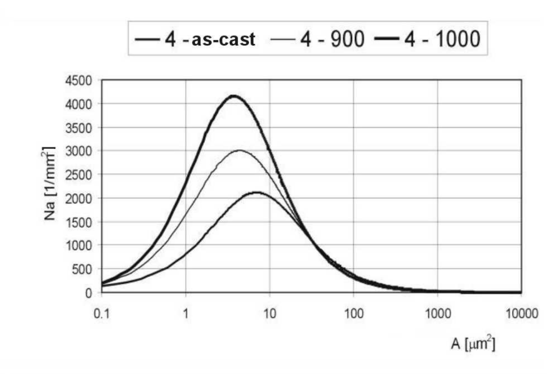

Fig. 5. Distribution of carbide amounts in area size function (C=2.55%, Cr=12.11%)

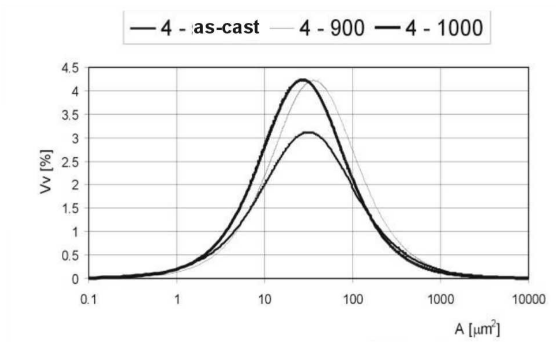

Fig. 6. Distribution of carbide volume fractions in them size function (C=2.55%, Cr=12.11%)

Table 2
Stereological parameters of carbides in as cast and austenitized state (C=2.55%; Cr=12.11%)

Parameters	As cast	900 °C	1000 °C
	Empirical average values		
A [μm²]	16.5	12.3	9.2
L_A [μm]	26.4	18.5	15.4
Vv [%]	15.9	16.0	15.4
Na [1/mm²]	9037	12911	16472
	Parameters of approximation function Na(A)		
U_N [1/mm²]	7452	10926	13770
W_N [μm²]	1.962	1.484	1.331
Z_N [1/mm²]	1.132	1.098	1.204
R	0.99	0.97	0.97
F	61	27	30
	Parameters of approximation function Vv(A)		
U_V [%]	10.27	12.63	12.59
W_V [μm²]	3.46	3.58	3.29
Z_V [%]	1.21	1.33	1.34
R	0.99	0.97	0.97
F	79	26	22

Significant differences in chromium content in describing melts exert an essential influence on over-cooled austenite behavior what decide about selection right heat treatment parameters. Therefore dilatometric tests selected melts (6, 11, and 22 %Cr) have been carried out and basis on them TTTc diagrams have been made – Figs 7, 8, 9.

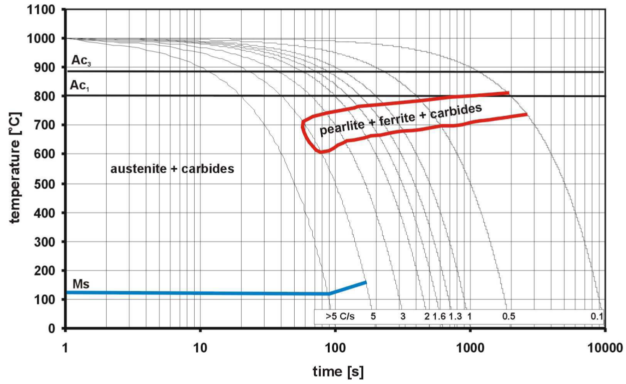

Fig. 7. TTTc diagram for melt C=1.52%, Cr=6.27%

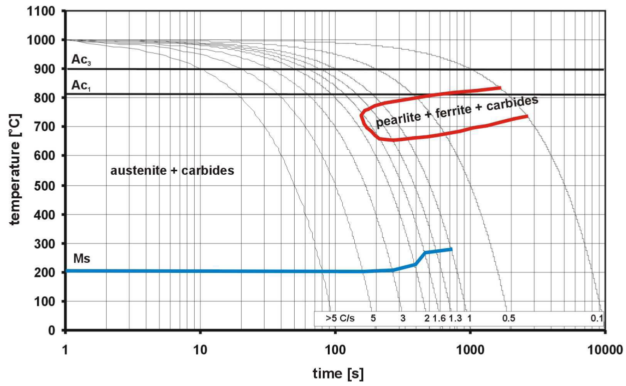

Fig. 8. TTTc diagram for melt C=1.57%, Cr=11.20%

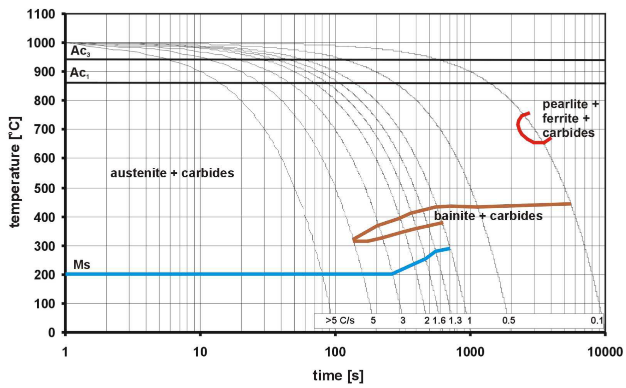

Fig. 9. TTTc diagram for melt C=1.50%, Cr=22.59%

High chromium cast iron is characterized by very high durability of over-cooled austenite and martensitic transformation occurs even for cooling with low speed i.e. 0.1 K/s. Microscopic picture of describing alloys in depend on chemical composition and crystallization process is differ in significant way, however heat treatment exerts little influence – microstructure selected melts are presented in Fig. 10 and 11.

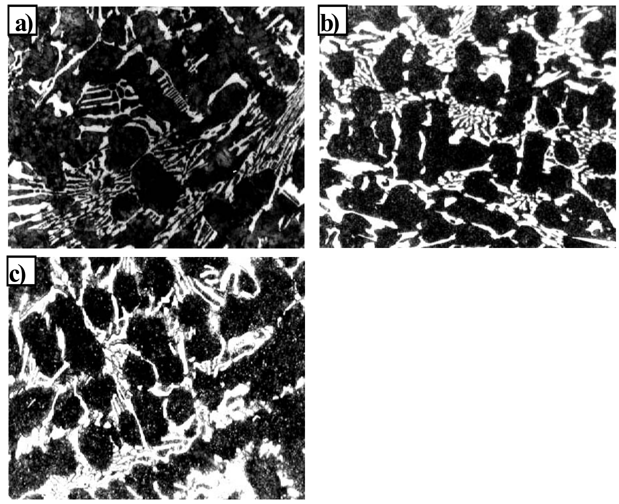

Fig. 10. Microstructures of chromium cast iron (C=2.55%; Cr=12.11%), a) – as cast, b) – 900°C, c) – 1000°C

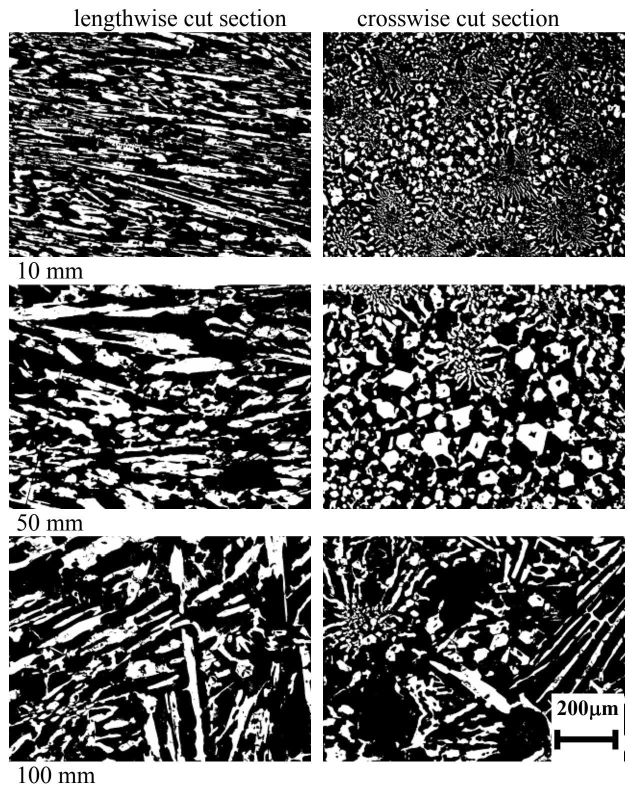

Fig. 11. Microstructure of chromium cast iron in function of distance from face (surface) of model casting ϕ30mm – C=3.55%; Cr=13.28%

4. Abrasive wear of chromium cast iron researches

Worked out by professor S. Jura materials resistance on erosion wear research method base on theoretical basis of erosion mechanics according to Bitter [7]. Bitter's equations permit to quantitative characterize the process of erosion wear, but for this the knowledge of such parameters as energy of wear by spalling E and machining R indicators as well as abrasion solid and abraded solid material parameters such as: Poisson ratio ν_1, ν_2; Young modulo E_1, E_2 as well as coefficient of dynamic elasticity Y. Determination of these parameters is possible only experimental. Erosion wear research method by professor S. Jura makes possible to determine abrasion parameters thereby to describe erosion process by mathematical function. Method consists of two fundamental parts. First is experimental put specimens made of tested material and model material to erosion in abrasive stream. The set of specimens numbers 70 pieces. Abrasion stream is put on specimen's surface with specific velocity V and with specific angle of falling α. Range of angle α is $15^o \div 75^o$ and velocity may be changed in range 30 to 100 m/s. In cycle of tests as standard are expected measurements of specimens weight loss for 8 angles α (15^o, 20^o, 25^o, 25^o, 45^o, 55^o, 65^o, 75^o) for specific abrasion stream velocity V. In Fig. 12 scheme of research stand for erosion in abrasion stream tests and shape of specimen are presented.

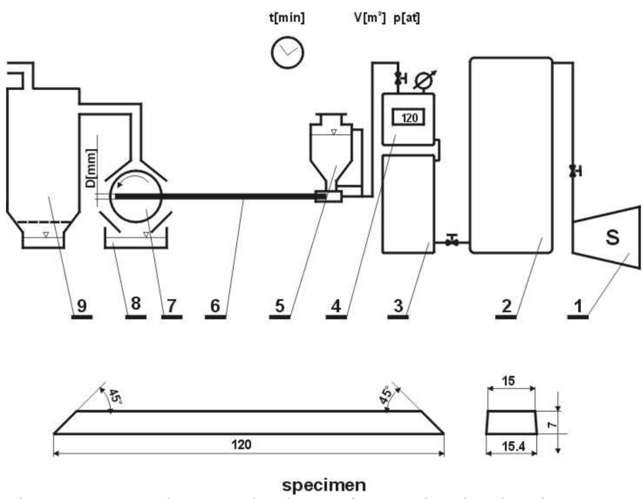

Fig. 12. Researches stand scheme for erosion in abrasion stream of solid particles tests and shape of specimen; 1 – compressor, 2 – air tank, 3 – filtering tank, 4 – measurement chamber, 5 – abrasive material tank, 6 – lance, 7 – rotary drum with set of specimens (70 pieces), 8 – used up abrasion material tank, 9 – dust collector

Second part is a determination abrasive parameters and work out diagrams of erosion wear basis on results of experiments. For these aim special computer software was written in Department of Foundry Technical University of Silesia In Gliwice. Software makes possible to determine parameters of erosion wear for one- and two-phase material. Its software fits experimental results into Bitter's equations by such selecting abrasion parameters E, R, H, Y as Bitter's equations in satisfactory way describing experiments. This process is controlled by parameters of statistic analysis.

Basis on determined abrasion parameters is possible, in further part of research, to work out graphs of erosion wear for tested material and search connections with other properties (e.g. mechanical, chemical composition, microstructure's parameters) of tested material.

In Fig. 13 course of erosion wear typical for chromium cast iron are presented. Continuous line shows total wear which is a sum of carbides phase presenting 15% of wearing surface and matrix presenting 85% of wearing surface. On graph could be seen that content of carbides phase is advantageous for lower falling angle of abrasive material that is, were machining mechanics is predominant. In case of spalling mechanics is predominant in erosion process chromium cast iron with shape of wear graph as presented not be recommended. Conclusion is as follows: chromium cast iron with high carbides phase friction should be applied on device elements exposed on erosion wear at low falling angle of abrasive material on working surface.

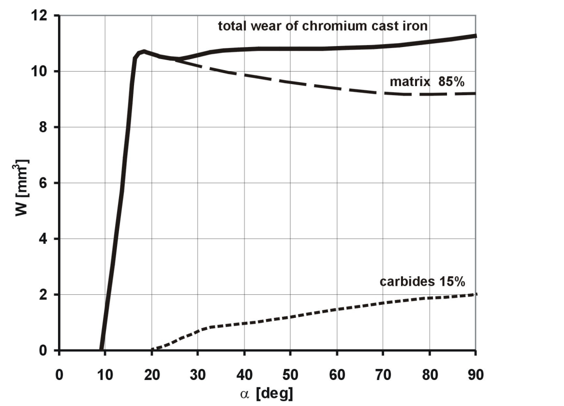

Fig. 13. Erosion wear characteristic for chromium cast iron as diphase alloy (matrix + carbides)

Development of Bitter's theory makes possible to searching best material for determined conditions of working elements work. Machines and devices designing should be start from determination of work conditions their elements. Basis on this should be selected right materials and in the trouble event in optimization process should be changed consruction if it is possible or selected other material. In Fig. 14 erosion wear characteristic for selected chromium cast irons in comparison with other alloys are presented.

5. Bimetal castings with chromium cast iron layer

Varied requirements putting to elements of machines and devices were and are causes come into begin complex constructions, made of different material. Also bimetallic castings made of two materials joined in cast process are numbered among complex constructions.

Bimetallic joint with cast technology may be made by means of one of following method:

I. placing in mould solid material heated to high temperature and next pouring them whit cast alloy,
II. pouring mould one by one with two cast alloys in one technology cycle,
III. pouring mould divided with metallic membrane at the same time with two differ cast alloys.

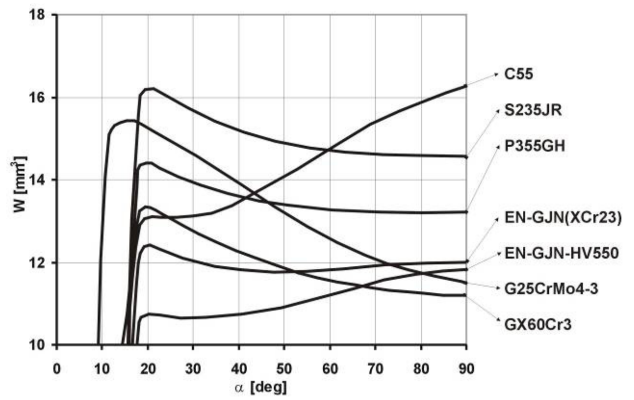

Fig. 14. Course of erosion wear characteristic for chromium cast irons (EN-GJN-HV550, EN-GJN-(XCr23)) in comparison with other alloys

Wear resistant chromium cast iron for the sake of specific properties is not devoid of disadvantages such as hard machining and weldability. For this reason gave rise conception of using, in industry practice, elements joined in self, proprieties of constructional steel and abrasion wear resistant materials.

In Department of Foundry was worked out technology and application of bimetallic casting (steel- steel casting- chromium cast iron) [8, 9, 10, 29, 37] produced with two methods I and II.

METHOD I (steel plate – chromium cast iron)

Essence of this method is to obtain the joint steel (cast steel) element with cast iron element through pouring with liquid metal (cast iron) mould cavity with molded steel element.

Two-stages way of pouring are assumed, it consists in heating steel component with liquid metal (cast iron), which after knocked out finished casting are disjoined from steel element. Second, right, portion of cast iron poured after specific time would join with preheating to right temperature steel insert.

In Fig. 15 cross section of example (ready to pour) mould are presented. In researches worked layer (wear resistant) was made of chromium cast iron EN-GJN-XCrMo15-3 and as "reinforcement" plate, made of steel S235JR was used.

In order to determine the quality of joint the bimetallic slab was broken on testing machine. In Fig. 16 fracture zone of tested bimetallic casting are presented.

Besides fracture evaluation specimens for metallographic analysis were cut off. In Fig. 17 microstructure of boundary zone between steel plate and chromium cast iron layer in tested casting are presented.

Carried out researches allow to affirm that basic technology parameter which makes possible to make the laminar casting is steel plate preheating temperature, it should not be lower than 750°C. Additional factors which guarantee obtaining joint the plate and cast iron are:

- applying addition preheating layer of cast iron in lower part of mould,
- applying flux for facilitate joining plate and cast iron,
- applying insulating coat.

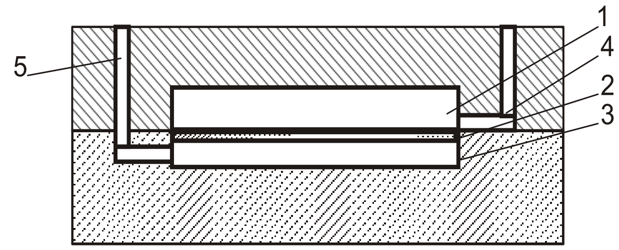

Fig. 15. Moulding of bimetallic casting scheme; 1 – cast iron worked layer, 2 – steel plate, 3 – heater, 4 – main pouring system, 5 - heater pouring system

Fig. 16. Fracture of tested bimetallic casting

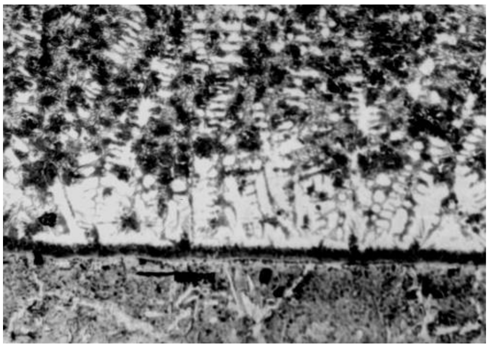

Fig. 17. Microstructure of steel plate cast iron joint

Laminar castings, steel-cast iron, are specific type of casting. The big amount of heat accumulated in mould causes crystallization of big carbides that unfavorably influencing on casting wear resistant. Even briefly microstructure analysis especially carbides size shows high diversity of carbides size and distribution. This diversity causes change of hardness on cross section of cast iron layer (Fig. 18). Hardness measurements were made after quenching from temperature 950°C with cooling worked surfaces with compressed air stream.

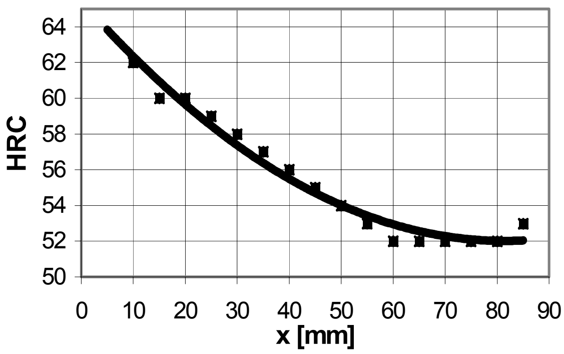

Fig. 18. Hardness of tested casting measured on cross section

METHOD II (cast steel – chromium cast iron)

Bimetallic casting, low carbon cast steel – chromium cast iron was recently arousing a big interesting due to possibility its application on crusher's hammer. Most simply hammer was selected for test (Fig. 19). Wear resistant cast steel G40CrMo4-3 and chromium cast iron EN-GJNHV600(XCr14) as tested materials were used in experiment.

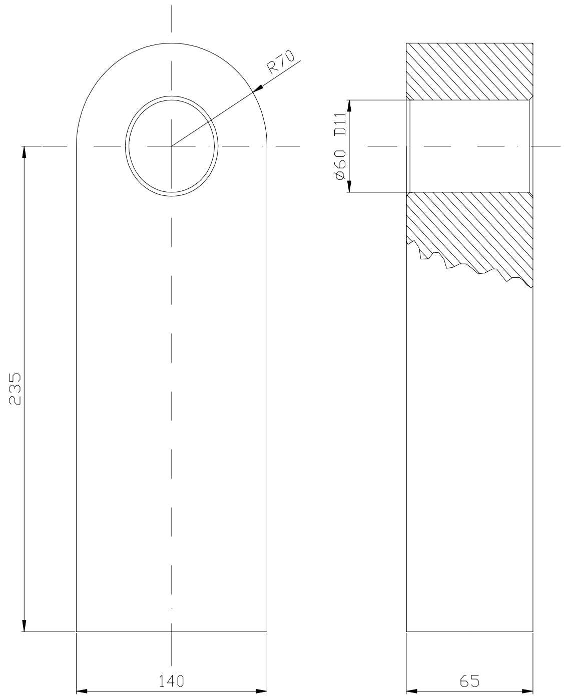

Fig. 19. Impact hummer and its basic dimensions

Basis on working drawing cast technology was worked out (Fig. 20). Mould was made of ordinary sand mix in three molding box, however core was made of core water-glass compound hardened with CO_2.

After melted both alloys mould was pored as first cast steel was poured and mould was filled in 2/3 part and next cast iron was poured. Basic problem connected with process of work out technology according method II is right pouring system construction due to securing separation of two different liquid metal stream pouring mould cavity.

6. Application of abrasive resistant chromium cast iron

Chromium cast iron is material which chemical composition is relatively wide, 2 – 4% C and 1,5 to ca. 30% Cr in whole range it is white cast iron. Besides chromium it usually include other alloy additions from which the most important are: Mo to 3% and Ni to 5%. Moreover its cast iron may include not large amount: Cu, V, Ti, W, B and N.

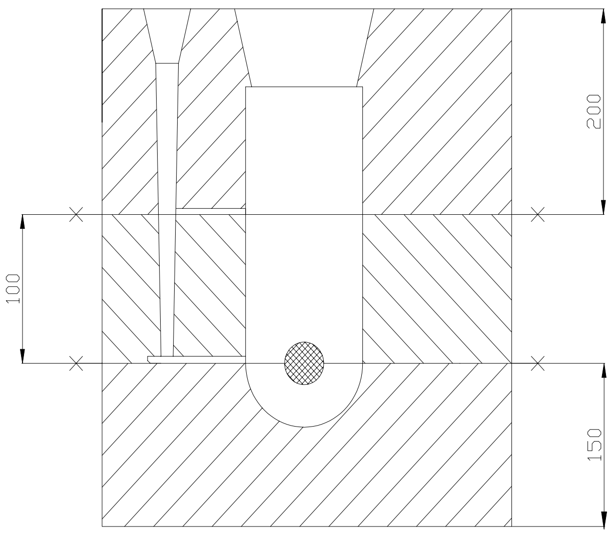

Fig. 20. Hammer arrangement in casting mould

High hardness of chromium cast iron contributes to its applications on casting elements of devices and machines working in intensive abrasive wear conditions in various branches of economy, and possibility of receive different matrix made allow to widen application range on abrasive-percussive wear conditions and working in high temperatures. Hence now chromium cast iron have wide application as abrasive wear resistant castings in such industry as:

- power engineering,
- cement, calcareous and gypsum industry,
- ceramic and processing aggregate industry,
- mining and coke engineering,
- foundry and metallurgy, etc.

Power engineering

In this industry are applied mainly castings made of high chromium cast iron about 15% Cr content as well as highest (23-30%) chromium content. Power engineering is biggest consumer of such kind of casting at home. These castings find application in such systems as:

- coal dust carburization, preparation and transport,
- dust removal,
- slag removal.

Typical carburization systems cover mills, dust pipe and burners – made of chromium cast iron.

Examples of castings produced for power engineering are presented in Figs 21 – 26.

Cement, calcareous and gypsum industry.

In this industry especially in mills even dozen years ago the basic material applied on lining and beaters were manganese cast steel (Hadfield). Now this material was in significant part replaced with different types of chromium cast iron. Thanks for this only in mills and clinker cooling bed wear of elements was decreased from 1kg (seventies and eighties) to 100g (now) castings per ton. Individual grade of cast iron find specific applications:

- low-chromium on permanent castings of cylpebs,
- chromium and nickel-chromium on ball 30 and 100 mm diameters,
- chromium (15 – 20 %) on armor plate and mill buffle,
- high-chromium (above 23%Cr) on elements of clinker cooling bed.

Ceramic and processing aggregate industry

Contact of metal elements with ceramics material and aggregate takes place in crusher, mill and every kind of chute. Wear in such conditions of work is abrasive-percussive. Unfortunately cast iron is low resistant on dynamic effect. However now in modern crushers chromium cast iron find application on armor plate, beater plate for medium size crushers and mills. Moreover in ceramic industry elements of press to stoneware pipe extrusion such as conveying paddle, worms, liners and cutters are made of chromium cast iron.

Mining and coke engineering

Similar to ceramic and processing aggregate industry, elements of machines and devices, which have contact with coal or stone wining are open, are open to intensive abrasion hence basic application of chromium cast iron:

- wining chutes in strip mine and coke chutes,
- sludge pump rotors and barrel,
- elements of crusher and sieves,
- elements of quenching car in coking plant.

Foundry and metallurgy

In foundry biggest wear takes place in shot blasting machine, pneumatic conveying systems and in every kind of mixers thus these devices are equipped with high abrasion resistance elements usually made of chromium cast iron. Among these element we rate:

- paddles and rotors of shot blasting machine,
- liners of leg pipe of pipe line for sand mix conveying,

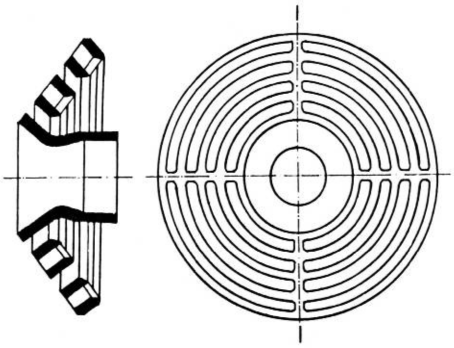

Fig. 21. Wobbler of air-dust burner

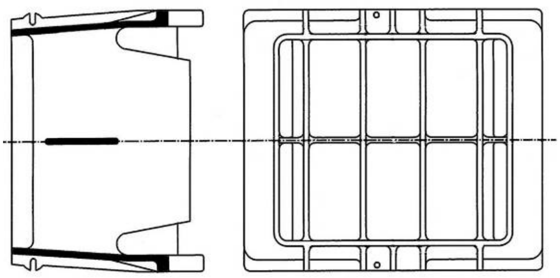

Fig. 22. Air-dust nozzle

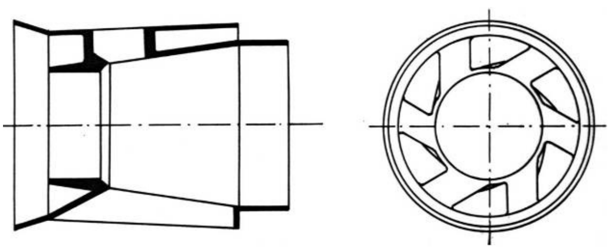

Fig. 23. Swirler of air-dust mixture

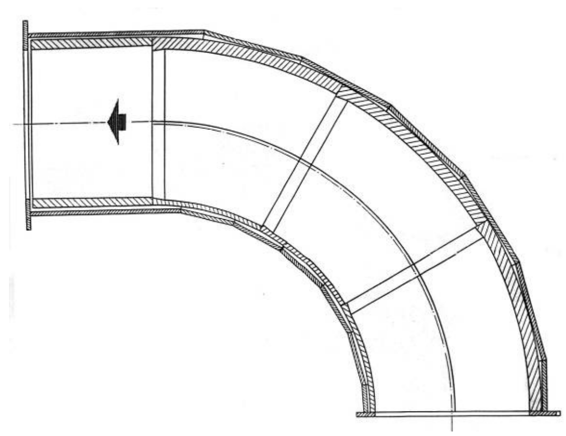

Fig. 24. Leg pipe of air-dust mixture with wear resistant inserts

- mixer blades and paddles,
- regenerators in sand mix regenerating systems.

However in metallurgy basic applications of chromium cast iron are:

- elements of ore conveyor,
- some metallurgical rolls,
- closure bell top of a blast furnace.

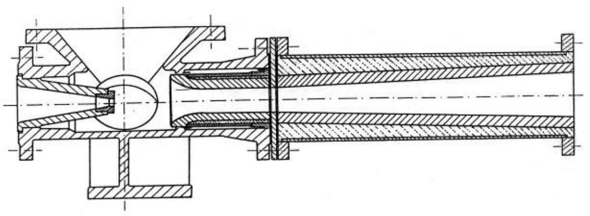

Fig. 25. Nozzle of air injector

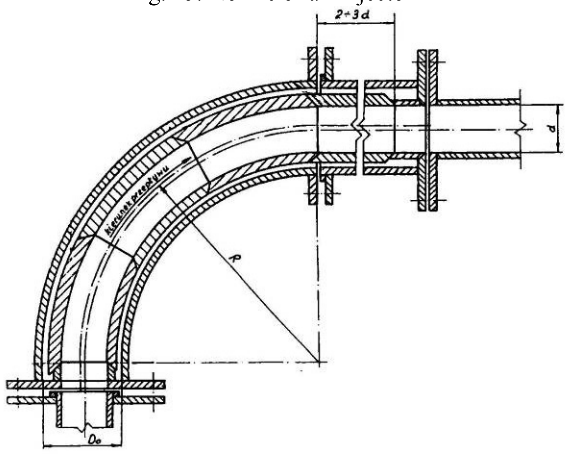

Fig. 26. Construction of leg pipe for ash removal systems also applies in various type of granular materials transporting devices

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