A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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NEW HIGH QUALITY MATERIALS FOR MACHINERY AND FOUNDRY DEVICES

NOWE WYSOKOJAKOŚCIOWE MATERIAŁY DO ZASTOSOWANIA W MASZYNACH I URZĄDZENIACH ODLEWNICZYCH

This paper presents the details rules of material selection predicted for machine parts. Hardness of most applied materials and layers manufactured by PVD method were given. The basic characteristics of new materials selected from alloys group: iron, cooper, aluminum were presented. Revealed its high wear resistance, corrosion resistance and significant mechanical properties.

Keywords: material design, physico-chemical properties, coatings, low carbon cast iron, nodular cast iron, aluminum bronze, silumin

W pracy przedstawiono uszczegółowione zasady wyboru materiału na części maszyn, podano twardość najczęściej stosowanych materiałów i powłok osadzanych metodami PVD. Przedstawiono podstawową charakterystykę nowych materiałów z grupy stopów: żelaza, miedzi i aluminium. Wykazano ich wysoką odporność na zużycie, korozję oraz znaczne własności wytrzymałościowe.

1. Introduction

Due to the nature of working conditions prevalent in foundry, machinery and foundry devices should be characterized by an unique service life and operational reliability, particularly in automated molding lines. In most cases they are destroyed as a result of abrasive wear. The type of the load and stresses caused by them also require high mechanical properties. Therefore, the aim of this study is to present characteristics of new high quality materials worked out in Department of Materials Engineering and Production Systems at Technical University of Lodz. These materials should be used by machinery and foundry devices designers.

2. Principles of material selection

Based on literature data [1, 2] and scientific research as well as author experience a new principles of material selection predicted for machinery and construction devices were worked out. They are presented in Fig. 1.

It results that analysis necessity of several materials from which most beneficial should be chosen, as well as detailed stresses analysis and final material choice should be done.

Next, within product improvement and within the innovation range new materials into service should be introduced examples of which were presented in this paper.

3. Hardness characteristics of selected materials

Tabel 1 presents hardness of selected materials, which may constitute friction pair or abrasive material [3].

Hardness of coatings manufactured by PVD method and its melting point were presented in Table 2 [3].

From presented in tab. 1 and 2 data results that in case of quartz or corundum as abrasive material even steel or cast iron with martensitic microstructure undergo of failure. Much more intensive abrasive wear process undergo materials under the influence of titanium nitride (TiN) or silicon carbide (SiC) and boron (B_4C). Increase of abrasive wear resistance can be obtain only by deposition of various kinds of layers, especially composite coatings. In figure 2 (a÷f) were illustrated structural diagrams of modern coatings fabricated by PVD methods [4].

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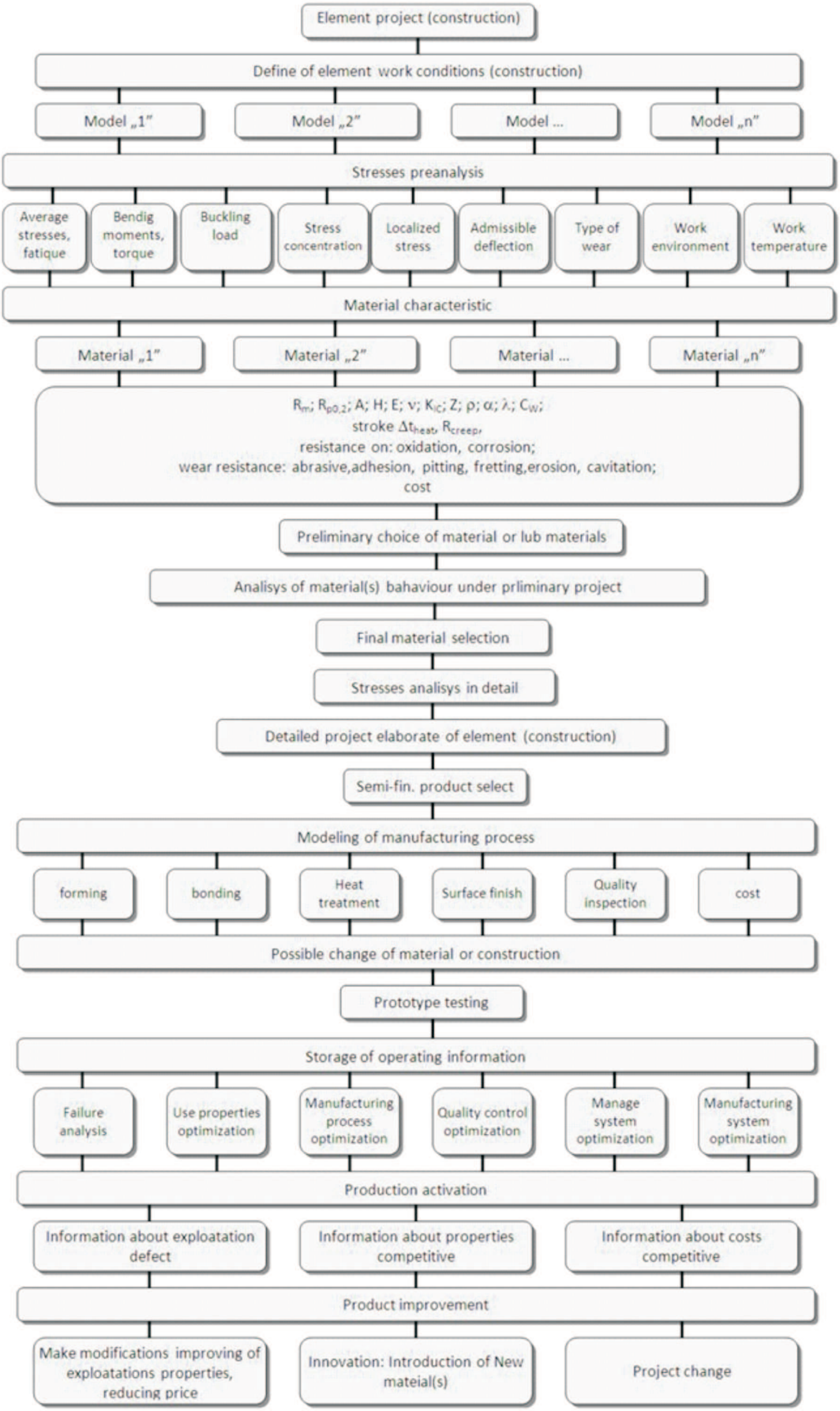

Fig. 1. Principles of material selection on machinery and construction devices

TABLE 1

Hardness of selected materials

Material	Hardness	
	HV	HB
Plastic material		2,5÷52
Silicon brass		90÷100
Steel bronze		70÷120
Lead bronze		19÷25
Tin bronze		80÷120
Silicon bronze		90
Soft steel	126÷158	120÷150
Hard steel	653÷772	HRC 58÷63
Cast iron	147÷274	140÷260
Calcite	109	104
Quartz	1120	
Topaz	1427	
Corundum	2060	
Diamond	10060	
Carburized case	> 697	HRC > 60
Nitrided case	650÷1200	
AlN	1230	
TiN	2100÷2400	
SiC	2600	
B_4C	3000÷4100	

Composite coatings, in its external part fulfil functional requirements ex. anti-friction properties, anticorrosive, thermal insulation, decorative etc.; in internal part assure of well coherence between coating and substrate and could be an additional prevent

TABLE 2

Hardness of coatings deposited by PVD method and its melting points

Coating	Hardness HV	Melting point °C
TiN	2100÷2400	2950
ZrN	1600÷1900	2980
TiC	2800÷3800	3070÷3180
ZrC	2600	3445÷3530
HfC	2700	3890
TaC	1550÷1800	3780÷3985
NbC	1800÷2400	3480÷3610
VC	2800÷2900	2650÷2830
TiO_2	1100	1867
Al_2O_3	1800÷2500	2047
BeO_2	1500	2550
DLC[3]	1250÷1650	–
NCD[4]	9000÷9500	–

[3] – amorphous carbon layers a: C-H (ang. Diamond Like Carbon)

[4] – nanocrystalline diamond layers (ang. Nanocrystalline Diamond)

from ex. high thrust (pressure) or penetration inside of coating by reactive matter in result of structural leak or exploitation of external sublayer. An example of such composition are coatings applicated for heat prevent of blade gas turbine determinate by TBC symbol (thermal barrier coatings). Composite coatings consist of modulated multilayer coatings too, its scheme is illustrated in Fig. 3 (a÷c) [4; 5].

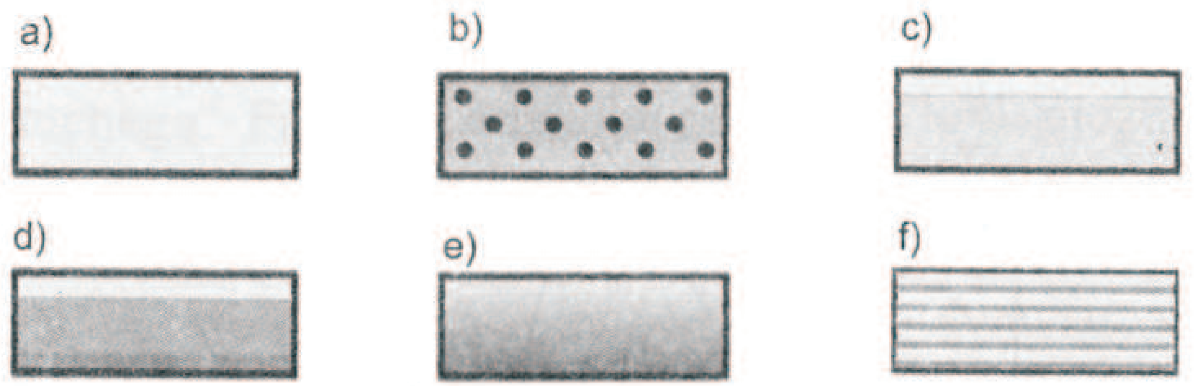

Fig. 2. (a÷f). Structural diagrams of modern PVD coatings; a – unary- or multicomponent single-layer coatings [ex. TiN, Ti(C, n), (TiAl)N]; b – multophase composite coatings ex. TiC/Al_2O_3; c – coatings and composition of coating/diffusion layer – "duplex" type ex. TiN/nitrided layer; d – trilayers coatings ex. $TiC/TiN/Al_2O_3$; e – gradient coatings ex. $Ti(C_x N_{1-x})$, $(Ti_x Al_{1-x})N$, where x – fluently changing in function of distance from external coating surface; f – multilayer coatings

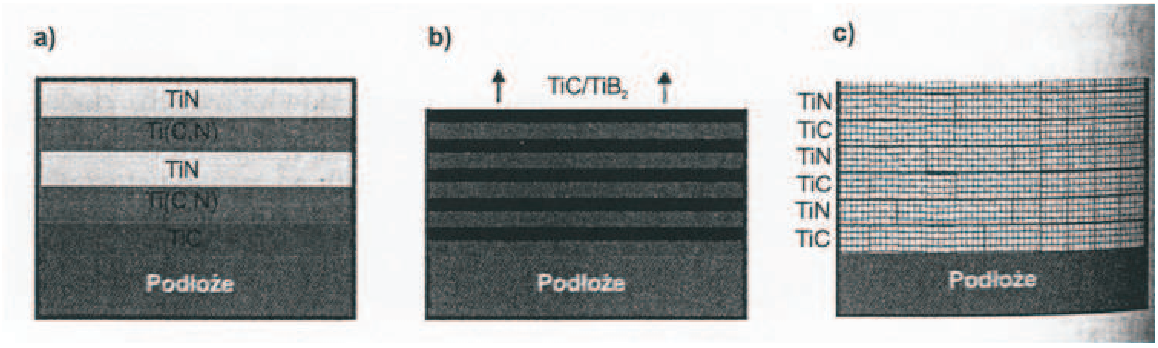

Fig. 3. (a÷c). Diagrams of three basic types of modulated multilayer coatings

Those are multilayer coatings with high number of single layers, being part of nanostructural materials. About its properties decide, so cold, modulation parameter defined as a sum of two adjacent sublayers.

4. New high quality materials

In relation to multilayer composite coatings it can be applied for multilayer products. Their construction is presented in Fig. 4.

Most often, in this way laminar products, in steel (cast iron) – alfinated layer – silumin system are made. In this case steel or cast iron fulfil functional conditions of machine or device part, while deposited by alfinated layer silumin has to perform other requirements ex. esthetic. Examples of alfinated coatings immersion deposited in AlSi11 silumin is illustrated In figure 5 (a÷c).

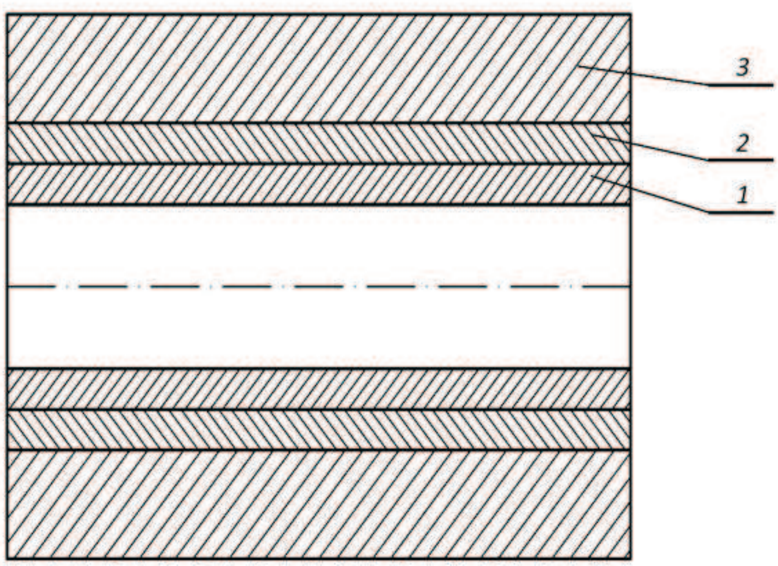

Fig. 4. Construction scheme of laminar product; 1 – basic material meet the functional requirements, ex. steel or caststeel wear and corrosion resistant (sample); 2 – interlayer (ex. alphinized); 3 – external part made of for ex. silumin

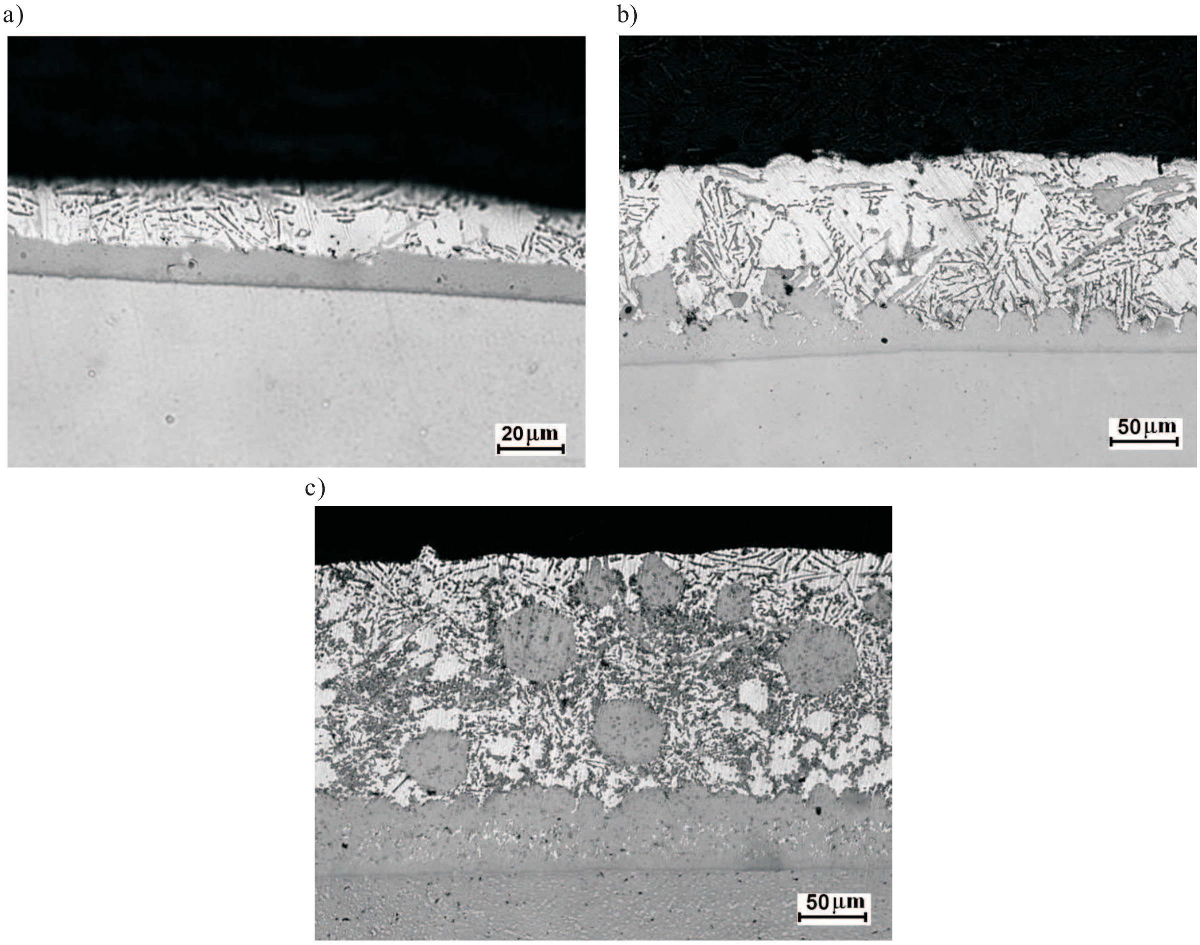

Fig. 5. (a÷c). Alfinated coating on steel: a – 1H18N9T; b – 4H13; c – SW7M

Characteristic is that in this coating are carbides occurred in those steels. An example of junction between AlSi8 and 4H13 steel by such coating is demonstrated in Fig. 6.

It results that connection between steel and alfinated layer as well as silumin and mentioned layer is high enough. Presented example illustrates possibility of mass part decrease and in many cases costs too. Material with high wear resistance, having in mind significant strength resistance, is low carbon cast iron with nodular graphite obtained in a raw state. Nodular graphite in low carbon cast iron can be obtained by slag treatment causes its deoxidize and desulfurization. Below in Fig. 7 (a, b) is inserted an example of nodular graphite in low carbon cast iron.

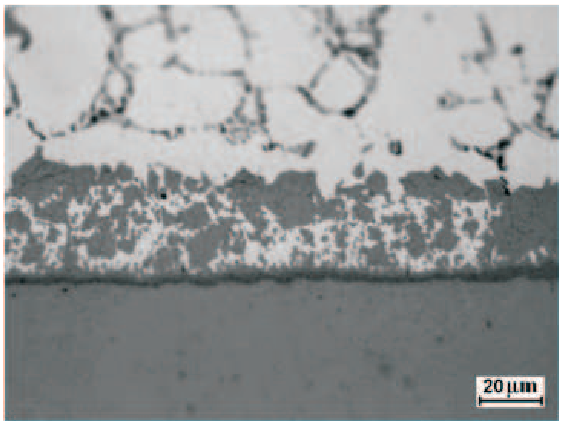

Fig. 6. Junction of AlSi8 silumin by alfinated coating with 4H13 steel

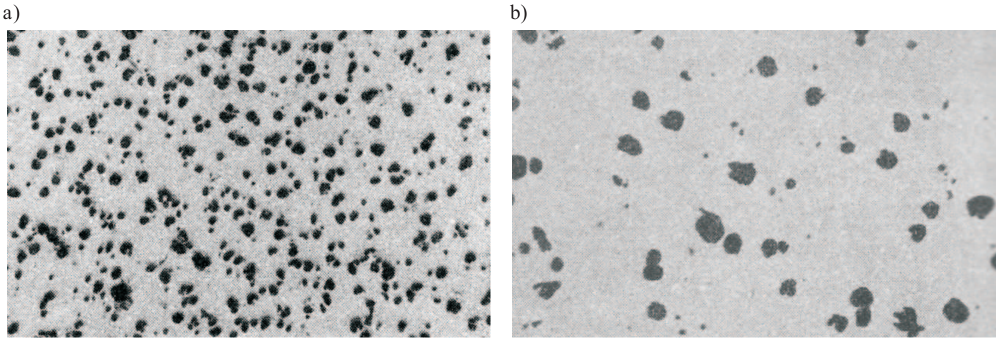

Fig. 7. (a, b). An example of nodular graphite in low carbon cast iron

Nodular graphite crystallize directly from liquid at the end of crystallize process of cast and from austenite after crystallize process ended in result of variable solubility of carbon. Chemical composition of low carbon cast iron is in the range: 0.90÷1.50% C, 1.90÷3.60% Si, 0.10÷0.50% Mn, 0.005÷0.05% P, 0.01÷0.005% S, 20÷70 ppm O2. By the addition, into low carbon cast iron, of Ni, Cu and Mo in dependence on cast cooling rate various kinds of microstructures: ausferritic, bainitic, martensitic or its mixture and nodular graphite in a raw state can be obtained. Examples of obtained microstructures are demonstrated in Fig. 8 (a÷f).

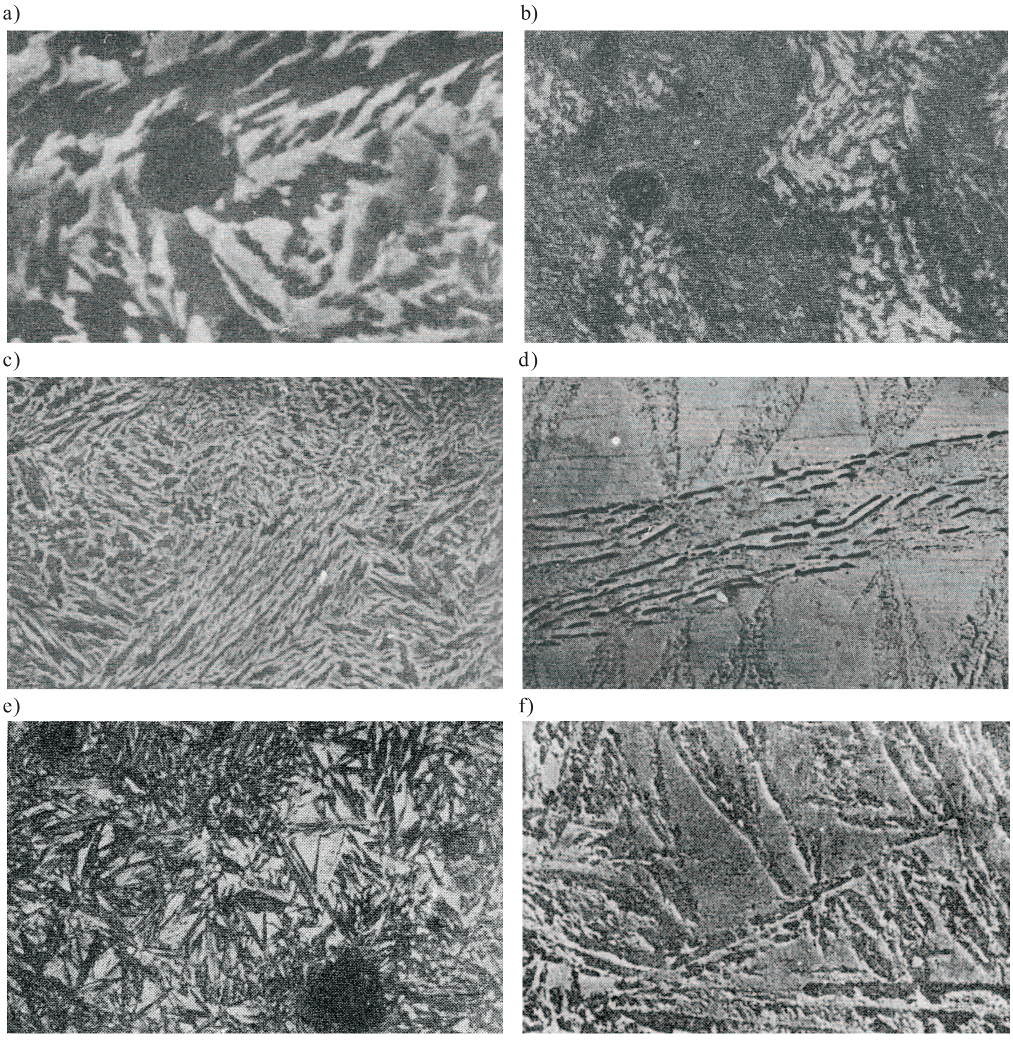

Fig. 8. (a÷f). Examples of low carbon cast iron microstructures obtained in a raw state: a – ausferrite (×6500); b – upper bainite (×800); c – upper with lower bainite (×2750); d – lower bainite with martensite (×4870); e – martensite (×500); f – martensite (×3400)

Mechanical properties of low carbon cast iron: Rm = 950÷1900 MPa, Rp0,2 = 800÷1750MPa, A5 = 0,0÷10,0%, 30÷60 HRC.

Another alloy with significant wear resistance, having in mind significant strength resistance is nodular cast iron with carbides with bainitc-martensite microstructure obtained in a raw state. Chemical composition of cast iron: 3.20÷3.80% C, 2.20÷3.00% Si, 0.35÷0.75% Mn, 0.00÷1.50% Cu, 0.50÷2.00% Mo and 0.00÷2.00% Cr. In dependence on cast iron chemical composition and cast cooling rate they can possess carbides in ausferritic matrix, upper and lower bainite, martensite or its mixture in a raw state. Its microstructure examples are presented below in Fig. 9 (a÷g).

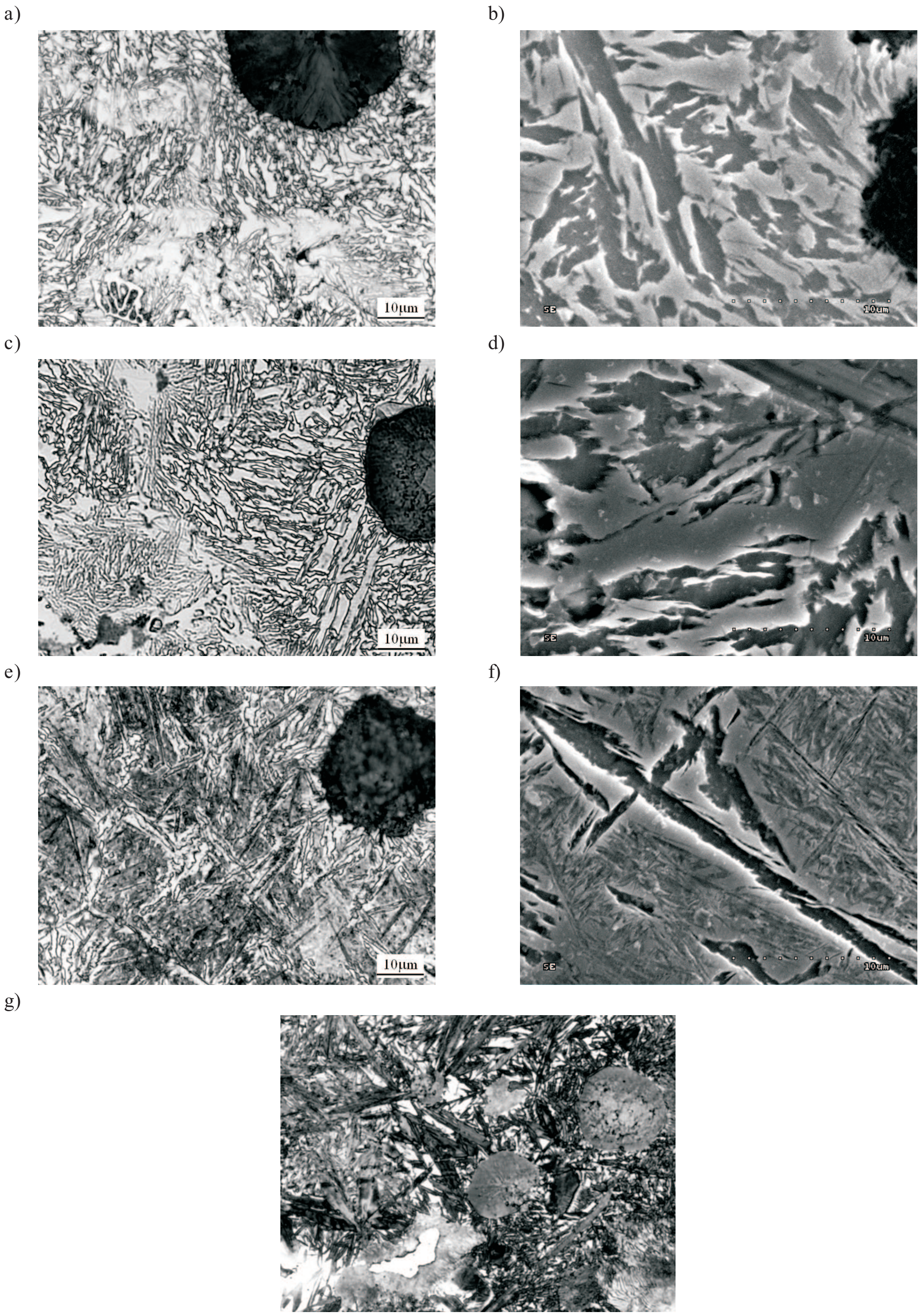

Fig. 9. (a÷g). Microstructure examples of nodular cast iron with carbides: a – ausferrite (×500); b – ausferrite; c – upper bainite (×500); d – upper bainite; e – upper with lower bainite; f – upper with lower bainite; g – martensite

Abrasive wear resistance of mentioned cast iron in compare with other materials is presented in Fig. 10.

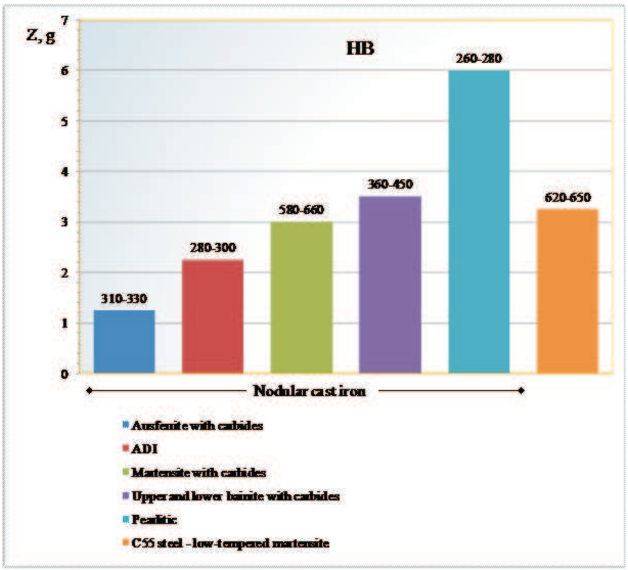

Fig. 10. Abrasive wear resistance of nodular cast iron with various microstructure and C55 steel

Mechanical properties of this cast iron: Rm = 800÷1300 MPa, Rp0,2 = 650÷1100MPa, A5 = 0.0÷5.0%, 280÷660 HB.

Bronze CuAl10Ni4Fe4 with Cr, Mo, W and V (one by one or together) is an alloy resistant on wear and corrosion with significant mechanical properties. Amount of additive contain in a range of 0.05÷0.80%. Representative Microstructure ex ample of bronze is presented in Fig. 11.

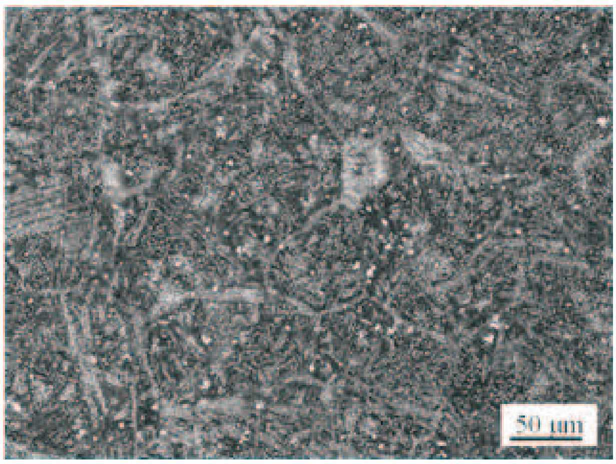

Fig. 11. Microstructure of CuAl10Ni4Fe4 bronze with additives of 1.30% Si, 0.60% Cr and 0.017% W. Phases: $\beta + \alpha + \gamma_2 + \chi_{FeCrMoWSi}$

Such significant abrasive wear resistant of this bronzes is obtained in result of $\chi_{FeCrMoWSi}$ phase release. Examples of bronze hardness without and with: Si, Cr, Mo, W are presented in Fig. 12.

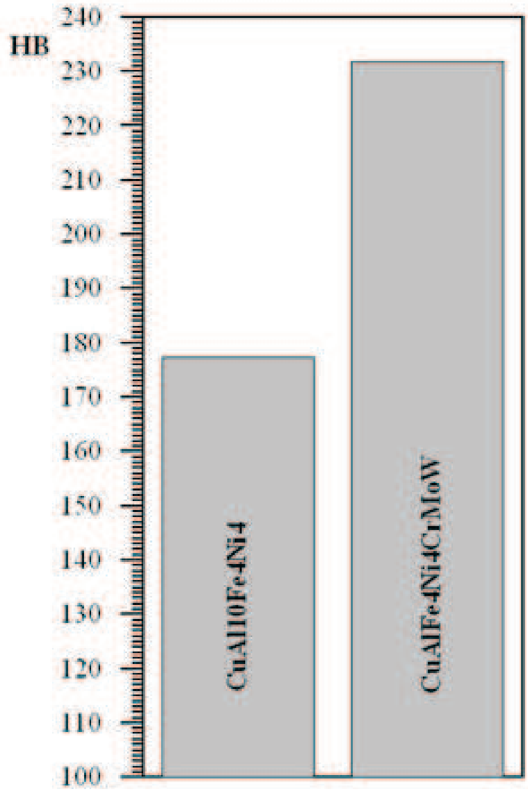

Fig. 12. Hardness of CuAl10Ni4Fe4 bronze and with additives of: Si, Cr, Mo and W

In Fig. 13 is showed CuAl10Ni4Fe4 bronze abrasive wear resistance without and with: Si, Cr, Mo, W.

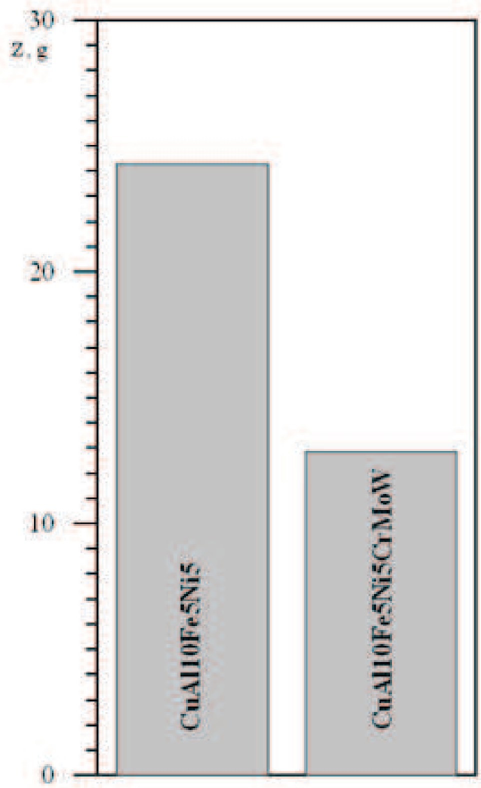

Fig. 13. Abrasive wear resistance of CuAl10Ni4Fe4 bronze and with additives of: Si, Cr, Mo and W

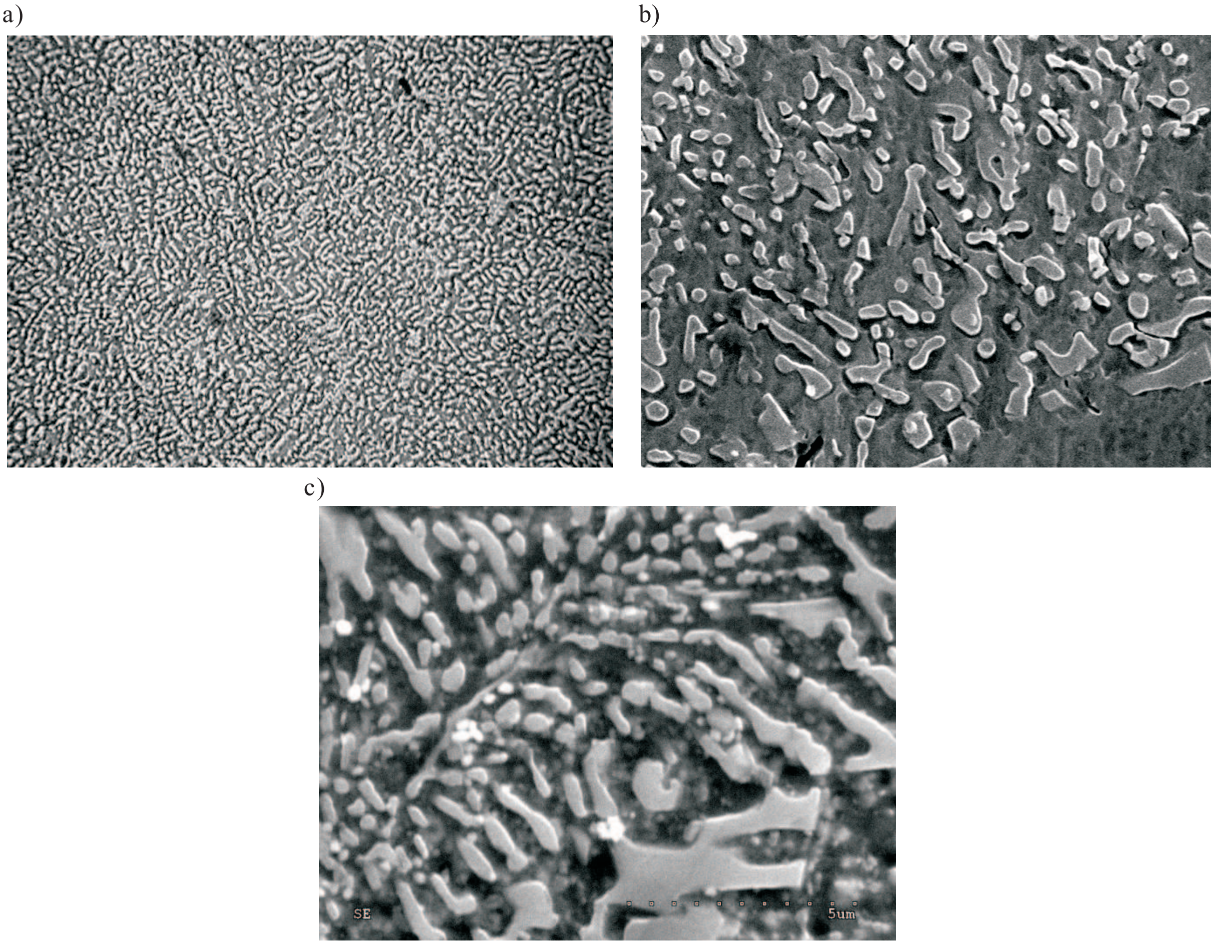

Fig. 14. (a÷c). Microstructure of AlSi7Ni4Cu2Mg0,5Cr0,3Mo0,3 silumin. Phases: α, AlSiCrMoNiFeTi, Al_3NiCu, Mg_2Si, Al_2Cu, eutectic mixture $\alpha + \beta$; a – raw state (×100); b i c – after release consolidation

From the data displayed in Fig. 12 and 13 results that alloy additives Si, Cr, Mo and W increase hardness of bronze up to 30% and wear resistance up to 50%. Also silumins hypo-, hyper- and near-eutectic with additives of: Cr, Mo, W and V in amount of about 1.00% in its group are characterized by the highest wear resistance, hardness and high mechanical properties.

It is caused by multicompound phases releases of AlSiCuFeNiMgCrMoWV, Al_3CuNi, $AlNiCu_3$, Mg_2Si types crystallizing pre-eutectic or eutectic. Microstructure example of this silumins is presented in Fig. 14 (a÷c).

Silumins are characterized by high use properties: R_m = 350÷550 MPa, $R_{p0.2}$ = 200÷400 MPa, A_5 = 0.5÷5.0%, HB = 120÷220.

5. Conclusions

To sum up were elaborated:

- detailed rules of material selection;
- new technology of fabrication the laminar products;
- new high quality materials in alloys group of : iron, cooper and aluminium;
- these materials and laminar products are particulary recommended for machinery and foundry devices construction because of high wear resistance and corossion

There are make investigations over improvement of presented materials and its manufacturing technologies.

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