MEHANIČKE OSOBINE POLUTVRDIH VALJAKA OD LIVENOG GVOŽĐA OSIGURANIH OSNOVNIM ELEMENTIMA

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REZIME

U našim livnicama, specijaliziranim za valjke od livenog gvožđa, uprkos slijeđenju najpreciznijih uputstava u vezi s procesom topljenja gvožđa, vanpećnom obradom mase, kalupljenjem i sušenjem kalupa (takozvani proces livenja), hlađenjem i usmjerenim očvršćavanjem odlivaka u kalupima, kao i u vezi s čišćenjem i naknadnom obradom valjaka, faktor izvedbe ostaje relativno nizak. Valjci moraju posjedovati dobre osobine iskorištavanja, koje su uvjetovane tvrdoćom, otporom i stabilnošću na visokim temperaturama. Ove osobine garantiraju visoku otpornost na habanje u uslovima suhog trenja i neočekivanih promjena stabilnosti temperature u procesu valjanja. Čak su otporni i na toplotni zamor, (zato što se valjci zagrijavaju na mjestu kontakta s valjanim komadom), visoko su otporni na iznenadne promjene temperature i na savijanje. Takođe, valjci moraju vršiti pritisak na materijale i osigurati visok kvalitet površina valjanih komada.

Analize počinju industrijskim proučavanjem odbijenih oblika koji se pojavljuju u proizvodnji valjaka od livenog gvožđa i nastavljaju se predstavljanjem rezultata nekih istraživanja, o čemu je uvod dat u časopisu «Mašinstvo», broj 1/2003. Ovaj rad predstavlja neka razmišljanja o mehaničkim osobinama, posebno tvrdoći valjka od gvožđa, osiguranih osnovnim hemijskim sastavom (C, Si, Mn, S, P) i nastoji izvući neke zaključke o optimalnom osnovnom sastavu ovih gvožđa namijenjenih za lijevanje valjaka. Rad također predstavlja rezultate nekih istraživanja u vezi s hemijskim sastavom gvožđa (s nodularnim ili lamelarnim grafitom) namijenjenih za livenje polutvrdih valjaka Utjecaj svakog od osnovnih hemijskih elemenata (C, Si, Mn, S, i P) iz sastava ovih gvožđa na tvrdoću, izmjerenu na kori i rukavcima predstavljen je u grafičkom obliku. Varijacija tvrdoće je također predstavljena grafički, sa vrijednostima jednakim ugljiku (C_{ekv}).

Ključne riječi: polutvrdi valjci od livenog gvožđa, osnovni hemijski sastav, tvrdoća, odbačeni oblici

THE MECHANICAL PROPERTIES OF THE SEMIHARD CAST IRON ROLLS ASSURED BY THE BASIC ELEMENTS

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SUMMARY

In our foundries, specialised in the cast iron rolls, in spite of following the most accurate guidance of the iron melting processes, of the outside treatments melting aggregate, of the moulding and drying of moulds (the so-called casting process), of the cooling and the directional solidification of the castings in the moulds, as well as of the rapping, cleaning and the subsequent processing of the rolls, the performance factor remains relatively low. The rolls must possess high exploitation qualities, which are determined by the hardness, resistance and high temperature stability. These qualities guarantee the high resistance at wear in the dried friction conditions and the unexpected temperature stability variation in the rolling operation. In addition, they assure the resistance at the thermal fatigue, (because the rolls are heated at the contact with the laminate), high resistance at the thermal shock stress, and the bending strain resistance. Also, the rolls must assure the clamping of materials, as well as the high quality of the laminate surface.

The analyses start from an industrial study on the rejected forms that appear in the production of cast iron rolls and continue by presenting the results of some research, the preliminary to which were presented in no. 1/2003 of "Masinstvo – Journal of Mechanical Engineering". This paper presents some considerations on the mechanical properties, especially the hardness of the iron rolls, assured by the basic chemical composition (C, Si, Mn, S, P) and tries to draw some conclusions upon the optimal basic chemical composition of these irons intended for roll casting. The paper also presents the results of some research regarding the chemical composition of the irons (with nodular and lamellar graphite) intended for casting of semihard rolls. The influence of each basic chemical element (C, Si, Mn, S, and P) from the composition of these irons on hardness, measured on the crust and the necks is presented in graphical form. The hardness variation is also graphically presented, with the carbon equivalent value (C_{ech}).

Keywords: semihard cast iron rolls, basic chemical composition, hardness, reject forms

1. UVOD

Tehnički uslovi, kojima su valjci od livenog gvožđa izloženi u toku korištenja su veoma različiti i često kontradiktorni. Dobivanje različitih fizičkih i mehaničkih osobina u različitim fazama livenja istog proizvoda livnice nailazi na različite tehnološke probleme u industrijskim uslovima. To podrazumijeva poznavanje različitih tehnoloških faktora, koji vode deformaciji ove opreme.

Valjci moraju pokazati dobre osobine eksploatacije, koje su određene tvrdoćom, otpornošću i stabilnošću na visokim temperaturama. Te osobine osiguravaju veliku otpornost na habanje u uslovima suhog trenja, kao i stabilnost pri neočekivanim promjenama temperature u procesu valjanja, otpornost na toplotni zamor (zbog toga što se valjci zagrijavaju usljed dodira sa valjanim komadom), veliku otpornost na iznenadne toplotne promjene, kao i na savijanje. Takođe, valjci moraju vršiti pritisak na materijale i osigurati visok kvalitet površina valjanih komada.

Valjci moraju pokazati veliku tvrdoću na kori i dalje u jezgru i na vratovima, koja će odgovarati mehaničkoj otpornosti i visokim radnim temperaturama. Ako se radi o kori, tvrdoću garantira količina cementita u strukturi gvožđa, ljuska valjaka mora imati grafita u svom sastavu kako bi se osigurala ova osobina.

Jedan od parametara koji određuju strukturu gvožđa namijenjenog za izljevanje valjaka je hemijski sastav. Ukoliko ne uvažavamo sastav, koji garantuje eksploatacione osobine svakog valjka na postolju valjaonice, dolazi do odbacivanja. Kao prvo, postizanje čvrstoće ljuske valjaka, određene standardima za svaku vrstu pojedinačno, uslovljeno je postizanjem strukture gvožđa (koje sadrži pearlit, cementit i grafit). Ova struktura je rezultat pravilnog hemijskog sastava, koji je ispoštovan pri izradi i modifikacijske obrade nodularnosti grafita u slučajevioma gdje se on koristi.

U našim livnicama, specijaliziranim za valjke od livenog gvožđa, uprkos slijeđenju najpreciznijih uputstava u vezi s procesom topljenja gvožđa, toplotnom vanjskom obradom mase, kalupljenjem i sušenjem kalupa (takozvani proces livenja), hlađenjem i usmjerenim očvršćavanjem odlivaka u kalupima, kao i u vezi s čišćenjem i naknadnom obradom valjaka, faktor izvedbe ostaje relativno nizak. U industrijsku analizu su bila uključena punjenja valjaka različite tvrdoće (polutvrdi, tvrdi), s određenom i neodređenom korom, u simpleksnom ili dupleksnom procesu livanja. Glavna oštećenja koja se javljaju u težini ili na površini valjaka predstavljena su grafički u svojoj različitosti na slici 1.

Od ukupne količine škarta, lunkeri u jezgru odlivaka su uzrok tome kod više od 25% škarta, a razlozi nastajanja lunkera su različiti. Pukotine (uzdužne ili poprečne) čine gotovo 20% od ukupne količine škarta.

1. INTRODUCTION

The technical conditions, which are imposed to the cast iron rolls in the exploitation period, are very different and often contradictory. The obtaining of various physical and mechanical properties in the different points of the same foundry product meets difficult technological problems in industrial conditions. This supposes us to know many technological factors, which lead to deformation of this equipment.

Rolls must present high exploitation qualities, which are determined from the hardness, resistance and high temperature stability. These qualities ensure high resistance to wear in dried friction conditions, as well as the stability at unexpected temperature variations in the rolling operation, resistance at the thermal fatigue (because the rolls are heated at the contact of the laminate), high resistance to thermal shock stress, as well as bending strain. Also, the rolls must assure the clamping of materials, as well as the high quality of laminate surface. The rolls must present high hardness at the crust of rolls and lower in the core and the necks, adequate to mechanical resistance in the high work temperature as well. If in the crust, the hardness is guarantied by the quantities of cementite in the structure of irons, the core of rolls must be content graphite, to assure this property.

One of the parameters, which determine the structure of the irons intended for roll casting, is chemical composition. If we do not respect the composition, which guaranties the exploitation properties of the each roll in the rolling mill stand, it leads to rejection. First, the hardness achievement of the crust of rolls, fixed strictly by the standards for each type in part, is conditioned by the achlevement of the structure of iron (which contains pearlite, cementite and graphite). This structure is a result of the correct chemical composition, which is respected at elaboration, and the modification treatment of the graphite nodularity, in the case of irons with nodular graphite.

In our foundries, specialised in the cast iron rolls, in spite of trying the most accurate guidance of the iron melting processes, of the outside treatments melting aggregate, of the moulding and drying of moulds, the so-called casting process, of the cooling and the directional solidification of the castings in the moulds, as well as of the rapping, cleaning and the subsequent processing of the rolls, the performance factor remains relatively low.

The industrial analysis included charges of rolls from different hardness classes (semihard, hard), with definite and indefinite crust, in simplex or duplex cast processes. The main defects, which appear in the weight or on the surface of the rolls, are presented in their great variety in Figure 1, in graphical form.From the total quantity of rejects, the pockets in the mass of the castings cause more than 25%. The causes of presence of the pockets are various. The cracks (longitudinal or transverse) represent almost 20% from the total mass of rejects.

Izbjegavanje nastajanja napuknuća je veoma složen zadatak, koji zahtijeva poštivanje odgovarajućih tehnologija proizvodnje valjaka, posebno kad je u pitanju hlađenje kod livenja.
Većina napuknuća se formiraju na temperaturi od 1000^{0}C, kada je mehanička čvrstoća livenog gvožđa veoma smanjena. Hladna napuknuća se javljaju na temperaturi nižoj od 550^{0}C, u području elastične deformacije, a nekada čak i na temperaturi okruženja. Raspodjela ovih odbačenih oblika, od ukupne količine napuknuća (20%) predstavljeno je grafički na slici 2.
Sljedeća grupa oštećenja koja vode odbacivanju se odnosi na neodgovarajuću dubinu tvrde kore valjaka. Ta oštećenja se mogu sastojati od nedovoljne ili prekomjerne debljine kore, umjesto one koja im je propisana po odredištu. Nejednaka debljina visine kore, na strani valjanja takođe vodi odbacivanju. Količina škarta valjaka, uzrokovana neodgovarajućom tvrdoćom kore (na strani valjanja) kao i rukavaca valjaka čini približno 9% od ukupnog broja odbačenih oblika. Nedovoljna ili prekomjerna dubina tvrde ili polutvrde kore valjaka uzrok je odbacivanja kod dodatnih 10% odbačenih oblika. U 6% slučajeva, odbacivanje je uzrokovano oštećenjima konstrukcije ili nedostacima u sastavu.

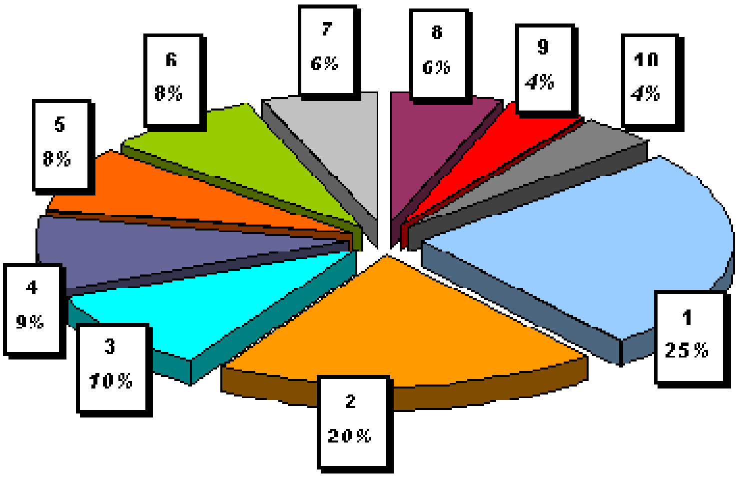
2. PODRUČJE TEHNIČKIH ANALIZA

Ovaj rad analizira izljevanje valjaka od gvožđa u simpleks proceduri, u kombiniranim oblicima (gvozdeni kalupi za koru i kalupni pijesak za vratove valjaka). Istraživanje se odnosilo na valjke polutvrde vrste s tvrdoćom između 33 i 59 Šorovih jedinica (219-347 Brineovih jedinica) za tvrdoću između 0 i 1, mjerenu na kori, i na valjke između 59-75 Šorovih jedinica (347-550 HB), za tvrdoću 2.
Ovo istraživanje je potrebno zbog brojnih oštećenja koja uzrokuju odbacivanje, počevši od faze izrade ovih gvožđa namijenjenih za livenje valjake. U skladu s onim što je prethodno rečeno, rezultat je da jedna od najvažnijih kategorija za škartiranje neodgovarajuća tvrdoća valjaka. Preporučljiva tvrdoća istih, na kori, kao i na rukavcima i u jezgru valjaka, po standardima, prikazana je u tabeli 1.
Hemijski sastav (osnovnih i legirajućih elemenata) koji se preporučuje za valjke polutvrde vrste livene od gvožđa s lamelarnim grafitom (tipa FS) i gvožđa s nodularnim grafitom (tipa FNS) prikazan je u tabeli 2.
Hemijski sastav uključuje i osnovne elemente (C, Si, Mn, S, P), i legirajućih elemenete (Cr, Ni, Mo), kao i sadžaj magnezijuma (u slučaju nodularnog gvožđa). U posebnim slučajevima, ova gvožđa mogu da sadrže i do 0,15..0,2% vanadiuma. Također, u slučaju izrade gvožđa s nodularnim grafitom namijenjeim za livenje gvožđa (tipa FNS), prihvatljiv je veći sadržaj fosfora, zbog toga što ovaj hemijski element učestvuje u otvrdnjavanju površine za valjanje kod valjaka.

Avoiding the occurrence of cracks is an extremely complex task, which requires an adequate respect of the roll production technologies, especially in the preparation of the chill for casting.
Most of the cracks are formed at about 1000^{0}C, when the cast iron mechanical strength is very reduced. The cold cracks appear at temperatures below 550^{0}C, in the elastic deformation area, and, sometimes, even at ambient temperature. The repartition of these forms of rejection, from the total quantity of cracks (20%) is presented graphically in figure 2.
Another group of defects, which lead to rejection, consists of inadequate depths of the hard crust of the rolls. These defects may consist of insufficient thickness of the crust, or of excessive thickness, instead of the specified ones by their subsequent destination. The uneven thickness on the height of the crust, on the rolling face, leads to rejection, too. The rejected rolls quantity, caused by the inadequate hardness of the crust (the rolling surface), as well as of the necks and the core of rolls, is approximately 9% from the total rejected forms. The insufficient or extended depth of the roll's hard or semihard crust is a caused with other 10% of the rejected forms. In 6% of the situations, the rejection is caused by structural and texture defects.

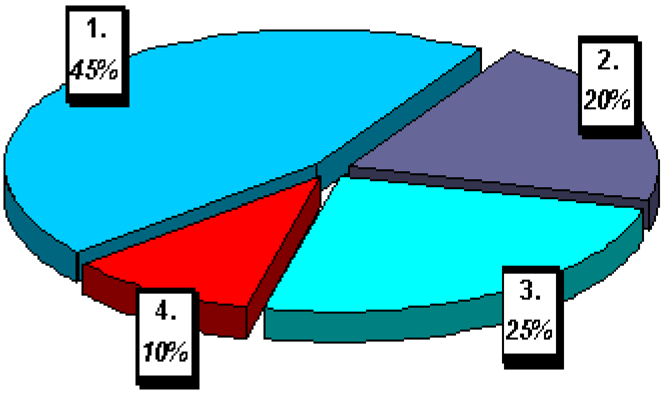
2. TECHNICAL AREA OF ANALYSES

This study analyses iron rolls cast in the simplex procedure, in combined forms (iron chill, for the crust and moulding sand, for the necks of the rolls). The research included rolls from the semihard class, with hardness, between 33..59 Shore units (219..347 Brinell units) for the 0 and 1 hardness class, measured on the crust, respectively 59..75 Shore units (347..550 Brinell units), for the class 2 of hardness.
This study is required because of the numerous defects which cause rejection from the phase of elaboration of these irons intended for cast rolls. According to the previous presentation, it results that one of the most important reject category is due to the inadequate hardness of the rolls. The recommended hardness of these, on the crust, as well as on the necks and in the core of rolls, fixed by the standards, is presented in table 1.
The recommended chemical composition (basic and alloyed elements) for the semihard class rolls, cast from lamellar graphite iron (type FS) and nodular graphite iron (type FNS) is presented in table 2.
The chemical composition include both the basic elements (C, Si, Mn, S, P), and the alloying elements (Cr, Ni, Mo), as well as the magnesium content (in the case of nodular irons). In special cases, these irons can contain up to 0,15..0,2% vanadium. Also, in the case of elaboration of irons with nodular graphite, intended for casting rolls (type FNS), a higher content of phosphorus is accepted, because this chemical element participates at the hardening of the rolling surface of the rolls



Slika 1. Raspodjela odbijenih oblika valjaka od livenog gvožđa: 1. lunkeri (cijevi); 2. pukotine (uzdužne i poprečne, toplotne ili hladne); 3. nedovoljna ili produžena dubina tvrde kore valjka; 4. neodgovarajuća tvrdoća na rukavcima i tijelu valjaka; 5. uklapanja i prijanjanja; 6. lunkeri i poroznost; 7. neodgovarajući hemijski sastav; 8. greške u strukturi; 9. neodgovarajuća veličina osnove; 10. ostala oštećenja

Figure 1. The Repartition of the Cast Iron Rolls Rejection Forms: 1. pockets (pipes); 2. cracks (longitudinal or transverse, at heat or at cold); 3. insufficient or extended depth of the roll's hard crust; 4. inadequate hardness at the necks and the body of roll; 5. inclusions and adherences; 6. shrinkages and porosities; 7. inadequate chemical composition; 8. texture defects; 9. inadequate base size; 10. other defects



Slika 2. Raspodjela pukotina: 1. uzdužne toplotne pukotine; 2. uzdužne hladne pukotine; 3. poprečne toplotne i hladne pukotine; 4. raštrkane i fine pukotine

Figure 2. The Repartition of the Cracks: 1. longitudinal cracks formed at hot; 2. longitudinal cracks formed at cold; 3. transverse cracks formed at hot and cold; 4. dispersed and fine cracks

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Tabela 1. Preporučljiva tvrdoća polutvrdih valjaka od livenog gvožđa

Table 1. The Recommended Hardness of the Semihard Cast Iron Rolls

Analizirana vrsta valjaka Analysed Rolls Types	Vrsta tvrdoće Class of Hardness	Preporučljiva tvrdoća ovih valjaka – Recommended Hardness for these Rolls			
		na kori (površini) valjaka on the Crust (Surface) of Rolls		u jezgru i na rukavcima valjaka on the Core and the Neck's of Rolls	
		[Šorova tvrdoća] [Shore Hardness]	[Brinelova tvrdoća] [Brinell Hardness]	[Šorova tvrdoća] [Shore Hardness]	[Brinelova tvrdoća] [Brinell Hardness]
FNS	0	33...42	218...286	30...40	195...271
FNS	1	43...59	294...347	30...40	195...271
FS	2	59...68	420...491	35...45	218...309
FNS	2	69...75	499...550	35...45	218...309

Tabela 2. Preporučljivi hemijski sastav polutvrdih livenih valjaka

Table 2. The Recommended Chemical Composition of the Semihard Cast Iron Rolls

Vrsta valjka Types of Rolls	Hemijski sastav, [%] - Chemical Composition, [%]								
	C	Si	Mn	P	S	Ni	Cr	Mo	Mg
FS	2,9...3,6	0,3...1,2	max 0,6	max 0,15	max 0,1	max 0,6	max 0,5	0,3...0,5	-
FNS	3,0...3,5	1,2...2,5	0,1...0,7	max 0,15	max 0,02	1,5...2,5	max 0,8	0,3...0,5	0,02...0,04

3. REZULTATI I DISKUSIJA

Istraživanje se odnosilo na polutvrde livene valjke, od nodularnog grafitnog gvožđa (tipa FNS), tvrdoće 1 i 2, s polutvrdom korom od 40-150 mm dubine. Skupina analiziranih valjaka predstavlja polutvrdu kategoriju, čiji su hemijski sastav i izmjerena tvrdoća prikazani u tabeli 3. Provjere tvrdoće, na oba vrata valjka, i na površini za valjanje su obavljane na podjednako udaljenim tačkama proizvedenih podloga, kako to standardi nalažu. Mjerene vrijednosti tvrdoća su predstavljene u tabeli 3.

Preporučuje se da vrijednost ekvivalenta ugljika, izračunata korištenjem formule (I) iznosi maksimalno 4,3%, za odlivke velike tvrdoće (u slučaju valjaka). Za izračunavanje vrijednosti ugljikovog ekvivalenta, formula (II.) je također prihvatljiva.

3. RESULTS AND DISCUSSION

The research includes semihard cast rolls, from nodular graphite irons (type FNS), hardness class 1 and 2, with the semihard crust of 40..150 mm depth. The lot of analysed rolls is representative for the semihard category, the chemical composition and the measured hardness of which is presented in table 3. The hardness checking, both on the two necks of the rolls, and on the rolling surface, are made in equidistant points of the manufactured surfaces, according to the standard stipulation. The measured values of the hardnesses are presented in table 3.

The value of the equivalent carbon, calculated by the formula (I.), is recommended to be maximum 4.3%, for castings with the heavy thickness (in this case of rolls). Also, for the equivalent carbon value calculation, the formula (II.) is accepted, too.

$$C_{ech} = C + 0,3\ (Si + P) – 0,03\ Mn + 0,4\ S + 0,07\ Ni + 0,05\ Cr\ [\%] \qquad (I.)$$

$$C_{ech} = C + 0,33\ Si + 0,1\ Ni\ [\%] \qquad (II.)$$

Tabela 3. Hemijski sastavi i izmjerena tvrdoća polutvrdih valjaka od livenog gvožđa
Table 3. The Chemical Composition and the Measured Hardness of the Semihard Cast Iron Rolls

Hemijski sastav [%] - Chemical Composition [%]					C_{ech} [%]	Tvrdoća [jedinica Brinell] Hardness [Brinell units]	
C	Si	Mn	P	S		na rukavcima on the Necks	na jezgru on the Crust
3,22..3,42	1,72..2,19	0,62..0,79	0,128..0,165	0,011..0,024	3,952 - 4,219	219..276	282..352
Ni	Cr	Mo	Mg				
1,49..2,22	0,36..0,72	0,18..0,28	0,021..0,029				

Tabela 4. Maksimalno smanjenje tvrdoće i debljina polutvrdog sloja
Table 4. The Maximum Decrease of Hardness and the Semihard Layer Thickness

Vrste valjaka Types of Rolls	Područje mjerenja Area of Measurement	Maksimalno smanjenje tvrdoće The Maximum Decrease of Hardness [HS]	Debljina polutvrdog omotača The Semihard Layer Thickness [mm]
FS	Na polutvrdom omotaču, Na rukavcima i jezgru on the semihard layer, on the necks and the core	- 8	35..70
FNS	Na polutvrdom omotaču, Na rukavcima i jezgru on the semihard layer, on the necks and the core	- 6	40..150

Najvažniji osnovni element sastava gvožđa je ugljik, koji utječe i na tvrdoću i na čvrstoću valjaka. U slučaju polutvrdih livenih valjaka, ovaj hemijski element varira između 3,0..3,5%, što osigurava preporučljivu tvrdoću kore (220..420 HB) i jezgra i rukavaca (220..300 HB). Hemijski sastav analiziran nakon perioda izrade, u slučaju sadržaja ugljika (3,22..3,42%) uklapa se u propisane vrijednosti, dok je tvrdoća između 219..276 HB, mjerena na različitim tačkama rukavaca, na istim stranama 222..352 HB (tabela 3). Maksimalno smanjenje tvrdoće i debljine polutvrdog omotača analiziranih valjaka od livenog gvožđa predstavljene su u tabeli 4.

Procenat silicija u ovim gvožđima namijenjenim za livenje valjaka usko zavisi od sadržaja ugljika. Rastom sadržaja ugljika i silicija u hemijskom sastavu ovih gvožđa debljina polutvrde kore se sužava, usljed porasta količine grafita.

Pojedinačni utjecaj svakog od njih je jači kad je jedan od elemenata u manjem, odnosno većem omjeru, međutim njihov utjecaj je sličan. Silicij ima utjecaj na oplemenjivanje grafita, jer je jedan od elemenata koji ima efekat grafitiranja i pogoduje prisustvu grafita u jezgru valjaka.

Varijacija tvrdoće u zavisnosti od sadržaja ugljika na kori i na rukavcima predstavljena je na slici 3, a silicija na slici 4. Hemijski sastav je pokazao da silicij varira između vrijednosti 1,64..2,19 %, koje su prihvaćene po standardima za livene valjke od gvožđa FNS vrsta (1,2..2,5%). Slika 4 prikazuje opadanje tvrdoće s porastom prisustva silicija u sastavu ovih gvožđa, ova varijacija je približna varijaciji ugljika.

Na donjoj granici sadržaja mangana, ovaj element ima jak efekat antigrafitiranja. Iznad 0,7% sadržaja mangana u gvožđu, karbidi se stabilizuju i tvrdoća se povećava. Iznad 1,0%, mangan se ponaša kao legirajući element, stabilizira cementit i indirektno otvrđuje gvožđe. Varijacija tvrdoće s ovim hemijskim elementom je prikazana grafički na slici 5.

U ovim gvožđima preporučljivo je da sumpor bude u minimalnim količinama, jer ovaj element ima nepoželjan utjecaj na mehaničke osobine – tvrdoća, kao i čvrstoća opadaju s porastom sumpora. Također, sadržaj sumpora u hemijskom sastavu utiče na nodularnost grafita, u slučaju gvožđa s nodularnim grafitom, te postoji potreba za njegovim smanjenjem do minimuma. U ovom slučaju sadržaj sumpora je striktno propisan i preporučljivo je da maksimalno iznosi 0,02 %.

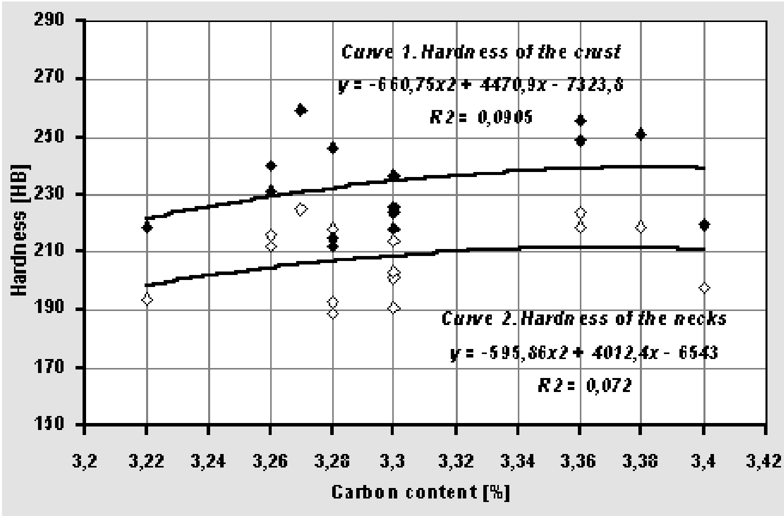
The main basic element of the iron composition is the carbon, which affects both the hardness and the strength of rolls. In this case of the semihard iron rolls, this chemical element varies between 3.0..3.5%, which assures the recommended hardness of the crust (220..420 Brinell units) and of the core and of the necks (220..300 Brinell units). The chemical composition, analysed after the elaboration period, in the case of carbon content (3.22..3.42%), fits in the established values, while the hardness is between 219..276 Brinell units, measured on the different points of necks, respectively between 222..352 Brinell units (table 3). The maximum decrease of the hardness and the semihard layer thickness of the analysed cast iron rolls are presented in table 4.

The silicon percentage in the irons intended for roll casting is in close dependence with the carbon content. With the growth of silicon and carbon content in the chemical composition of these irons, the semihard crust's thickness is narrowed, due to the growth of the graphite's quantity.

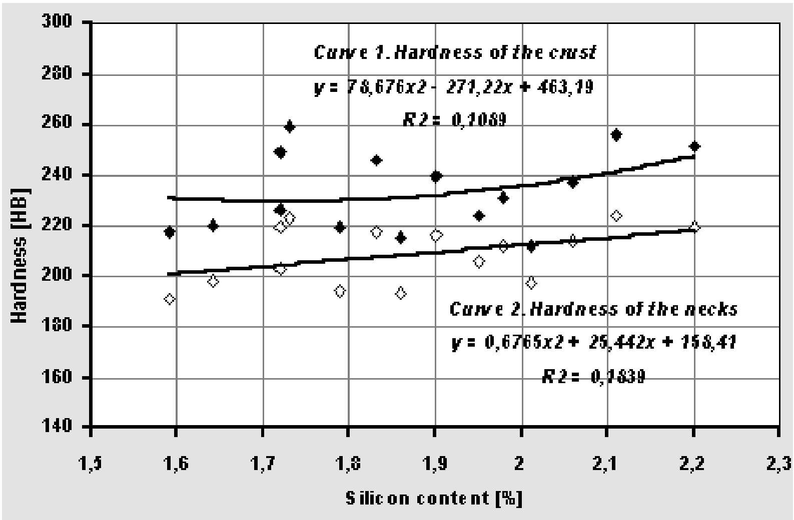
The separate effect of each of them is stronger when one of the elements is in a smaller or larger proportion accordingly but their action is similar. The silicon has influence upon the refinement of graphite, being one of the elements that have graphitesing effect and favours the presence of graphite in the core of rolls.

The hardness variation by the carbon and silicon content, on the crust and the necks, is presented in figure 3, respectively in figure 4. The chemical composition showed that the silicon varied between the values of 1.64..2.19 %, which are accepted by the FNS types cast iron rolls standard (1.2..2.5%). Figure 4 remarks the hardness diminution with the silicon content growth in the composition of these irons, the variation being simi-lar with a carbon variation. At a lower limit of manga-nese content, this element has a strong antigraphitesing effect. Above the 0.7% in the manganese content of irons, the carbides are stabilised and the hardness is increasing. Above 1.0%, the manganese acts like alloying element, stabilises the cementite, and implicitly hardens the irons. The hardness variation with this chemical element is presented graphically in figure 5.

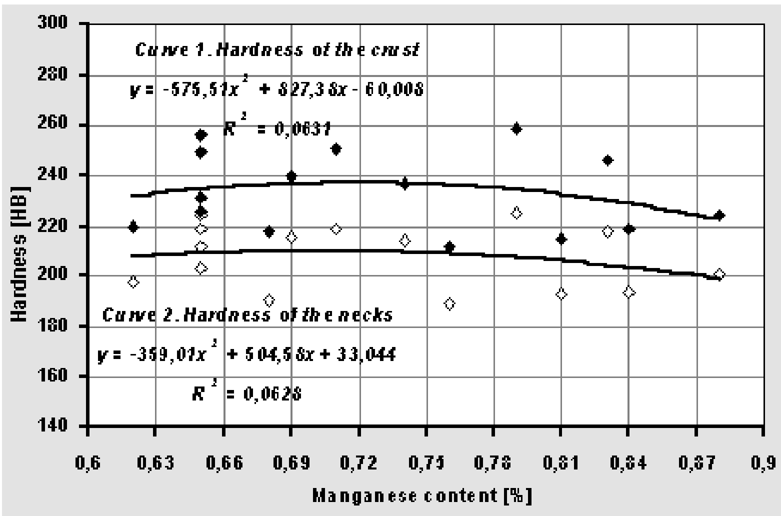
The sulphur in these irons is recommended to be in minimal quantities, because this element has an unfavourable effect upon the mechanical properties – the hardness, as well as the strength decreases while the sulphur content grows. Also, the content of sulphur in the chemical composition affects the graphite nodularity, in case of nodular graphite irons, so there is a need to reduce it to the minimum. In this condition, the sulphur contents are strictly imposed and are recommended to be at maximum 0.02 %.



Slika 3. Zavisnost tvrdoće od sadržaja ugljika kod polutvrdih valjaka od livenog gvožđa
Figure 3. Dependence of Hardness on the Carbon Content with the Semihard Cast Iron Rolls



Slika 4. Zavisnost tvrdoće od sadržaja silicija kod polutvrdih valjaka od livenog gvožđa
Figure 4. Dependence of Hardness on the Silicon Content with the Semihard Cast Iron Rolls



Slika 5. Zavisnost tvrdoće od sadržaja mangana kod polutvrdih valjaka od livenog gvožđa
Figure 5. Dependence of Hardness on the Manganese Content with the Semihard Cast Iron Rolls

Grafička prikaz tvrdoće (slika 6) predstavlja optimalnu vrijednost tvrdoće, na kori i u jezgru ovih valjaka, za analizirani hemijski sastav. Grafik je napravljen po ovim podacima i prikazuje zavisnost tvrdoće od prisustva sumpora. U slučajevima kad je prisustvo sumpora ograničeno na standardne vrijednosti, ovaj element ne može oštetiti strukturu gvožđa. Iznad ove vrijednosti, sumpor ima negativnu vrijednost na mehaničke osobine gvožđa.

U slučaju polutvrdih valjaka sadržaj fosfora je ograničen maksimalno na 0,2..0,3%. Zbog toga što ovaj element oblikuje tvrde smjese, potrebne na površini za valjanje, fosfor nema nikakvog utjecaja ako je ograničen na preporučljive intervale. Povećanje tvrdoće je grafički prikazano na slici 7, zajedno s porastom procenta fosfora u hemijskom sastavu.

Slika 8 predstavlja predstavlja varijaciju na kori, u jezgru i na rukavcima valjaka u skladu s vrijednostima ekvivalenta ugljika, izračunatih za svaki hemijski sastav pojedinačno. Može se primijetiti lagano povećanje tvrdoće na višim vrijednostima ekvivalenta ugljika kao i koncentracija oznaka tvrdoće na vrijednostima približnim 3,7..3,8%.

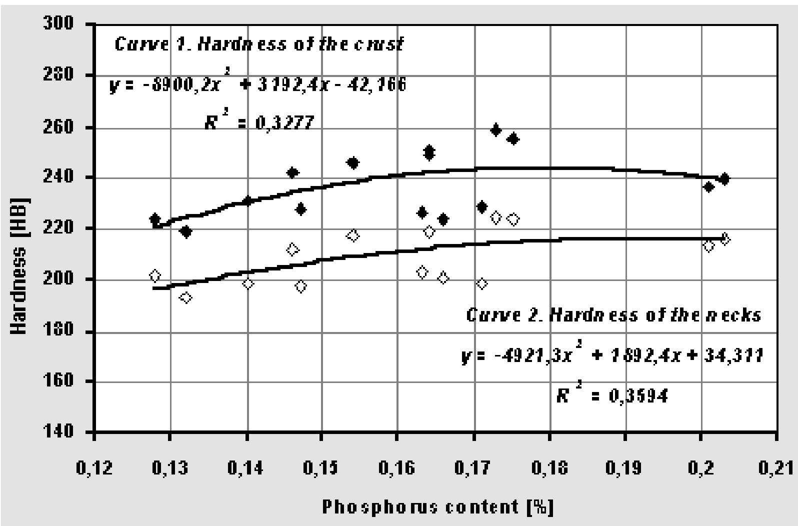
Imajući u vidu značajno opterećenje tokom rada valjaka, nametnute su im visoke mehaničke osobine (otpornost na habanje, otpornost na trošenje, otpornost na velike promjene temperature, tvrdoća na površine valjanja u jezgru i na rukavcima itd.). Kao posljedica toga, opada sadržaj ekvivalenta ugljika od 4,2% (njegove vrijednosti su u rasponu između 3,8 i 4,0%).

The graphical representation of hardness (figure 6) presents the optimal value of the hardness, on the crust and in the core of these rolls, for the analysed chemical composition. The graphic is made according to this data, and presents the dependence of hardness on the sulphur content. In the conditions of the sulphur content limitation to the standard values, this element cannot prejudice the structure of the irons. Above this value, the sulphur has a negative value upon the irons' mechanical properties.

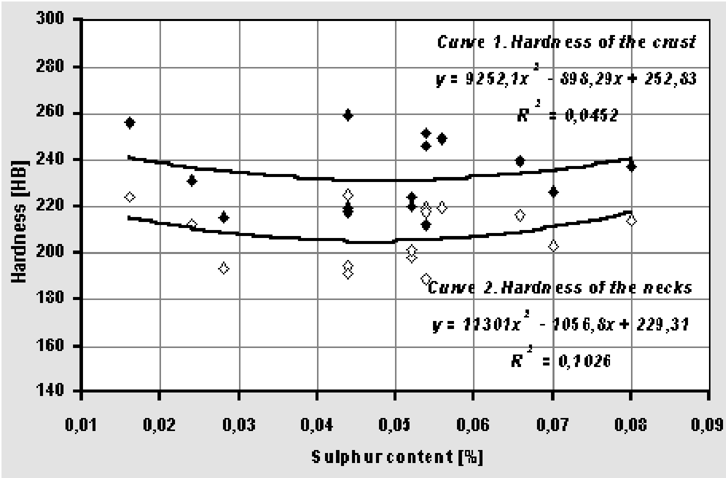
In the case of semihard rolls, the phosphorus content is limited to a maximum of 0.2..0.3%. Because this chemical element shapes tough compounds, needed in the rolling surface, the phosphorus does not have any effect, if limited in the recommended intervals. The increase of hardness can be observed in the graphic of figure 7, together with the growth in the chemical composition of phosphorus percentage.

Figure 8 presents the hardness variation both on the crust and on the necks and in the core of the rolls according to the equivalent carbon values, calculated for the each chemical composition in part. A smooth increase of the hardness is to be noticed at higher values of the equivalent carbon and also a concentration of the marks for hardnesses at values of approximately 3.7..3.8%.

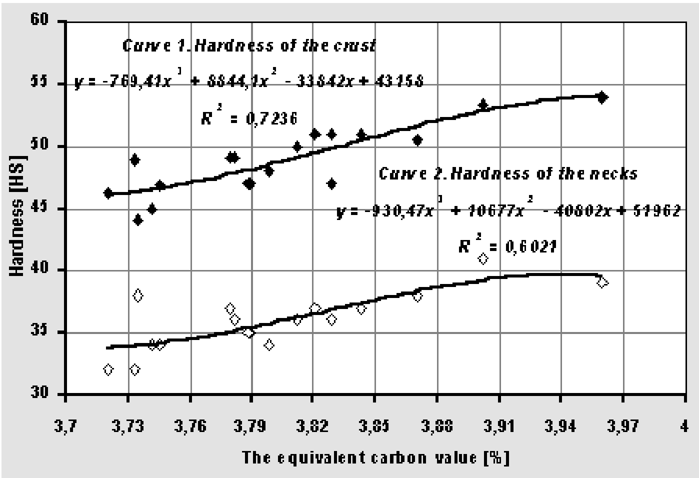
Having in view the considerable stress during the workings of the rolls, high mechanical properties (resistance to wear, resistance to abrasion, resistance to thermal shock, hardness on the rolling surface and in the core and on the necks, etc.) are imposed on them. Consequently the equivalent carbon content diminishes from 4.2% (its value stands between 3.8 4.0%), as the irons are hypoeutectic.



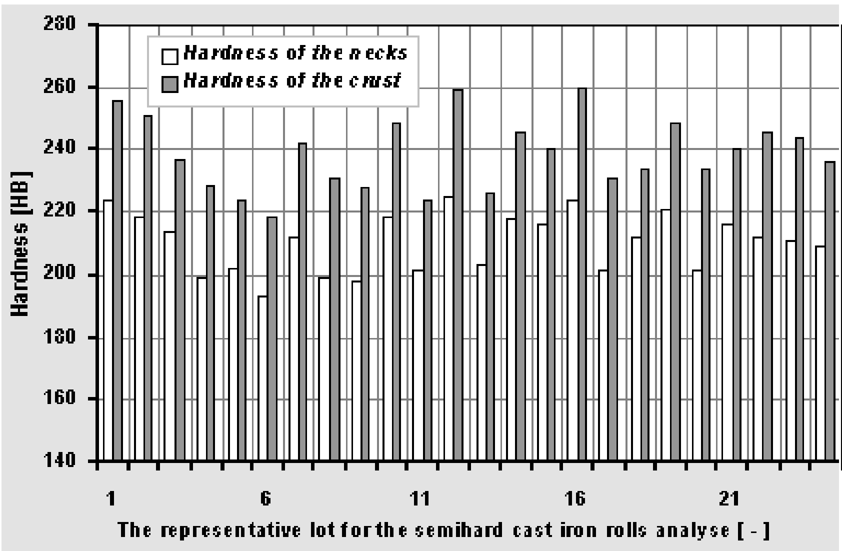
Slika 6. Zavisnost tvrdoće od sadržaja sumpora kod polutvrdih valjaka od livenog gvožđa
Figure 6. Dependence of Hardness on the Sulphur Content with the Semihard Cast Iron Rolls



Slika 7. Zavisnost tvrdoće od sadržaja fosfora kod polutvrdih valjaka od livenog gvožđa
Figure 7. Dependence of Hardness on the Phosphorus Content with the Semihard Cast Iron Rolls



Slika 8. Zavisnost tvrdoće (na rukavcima i kori polutvrdih valjka) od vrijednosti ekvivalenta ugljika
Figure 8. Dependence of Hardness (at Necks and with the Semihard Crust of Rolls) on the value of equivalent carbon



Slika 9. Analizirani skup vrijednosti ukupne tvrdoće na površini valjanja, na rukavcima i u jezgru polutvrdih valjaka o livenog gvožđa
Figure 9. The Representative Analysed Lot Hardnesses on the Rolling Surface and on the Necks and in the Core of Semihard Iron Rolls

4. ZAKLJUČCI

U fazi obrade gvožđa, tvrdoća se podešava putem kvaliteta metalne šarže i dodatnih materijala, kao i putem ispravnog izvođenja topljenja i obrade. Optimalan odnos sadržaja silicija i mangana je potreban i kad je u pitanju dodavanje osnovnih metala i fero-legiranog dodatka (FeSi, FeMn, SiMn).

- *Optimalne vrijednosti hemijskog sastava u glavnim elementima (C, Si, Mn, S, P) ovih gvožđa namijenjenih za livenje polutvrdih valjaka se mogu pronaći na dijagramima slika 3..7. Po njima optimalne vrijednosti mogu biti primjećene u koncetraciji svakog glavnog elementa, vrijednosti koje mogu osigurati odgovarajuću tvrdoću različitih dijelova valjaka. Posebnu važnost treba pridati sumporu iz ovih gvožđa, jer može utjecati na nodularnost.*
- *Za tanju polutvrdu ili tvrdu koru na površini za valjanje naknadno se dodaje FeSi, koji oslobađa silicij, odvajajući time dodatne količine grafita u dijelu kore i sužavajući time koru. Za kore veće dubine pravi se naknadni dodatak od karbida koji povećava količinu uobličenog tvrdog cementita;*
- *Glavni hemijski sastav mora biti u vezi s daljnjim dodavanjem legiranih elemenata, pri čemu se poštuje odgovarajući omjer nikla i silicija, kroma i nikla, molibdenuma i fosfora, sumpora i magnezijuma, pored optimalnog odnosa ugljika i silicija.*

4. CONCLUSIONS

In the processing phase of the irons, hardness is adjusted through the quality of the metallic charge and of the addition materials, as well as through a proper leading of the melting and of the processing. An optimum proportion between the silicon and the manganese contents is needed both from the basic metallic charges and from the ferro-alloy addition (FeSi, FeMn, SiMn);

- *The optimum values of the chemical composition in the main elements (C, Si, Mn, S, P) of these irons intended for the cast of the semihard rolls are to be found in the diagrams of Figures 3..7. According to them the optimal values in the concentration of each main element can be noticed, values that can assure adequate hardness of different areas of the rolls. Special importance needs to be given to the sulphur from these irons, as it can effect the nodularity;*
- *For a narrower semihard or hard crust on the rolling surface of the rolls, a supplementary addition of FeSi is made, which released the silicon, thus segregating supplementary quantities of graphite in the crust area and narrowing the crust. For crusts of increased depth a supplementary addition of carbides is made to heighten the quantity of the tough formation cementite;*
- *The main chemical composition must be correlated with further addition of alloying elements, respecting the adequate proportions between nickel and silicon, chrome and nickel, molybdenum and phosphorus, sulphur and magnesium, besides an optimal ratio of carbon and silicon.*

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