Vsebnost oligoelementov v specialnih jeklih in njihov vpliv na lastnosti jekel v predelavi in uporabi

Content of residuals in special steel grades and some observations of properties influenced by them

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UVOD

Pred dvajset in več leti so bile v strokovni literaturi razprave o oligoelementih prava moda. Po objavah v zadnjih letih bi sodili, da te problematike skoraj ni več, jeklarje pa le vsakodnevno mučijo težave izpolnjevanja omejitev, ki postajajo iz dneva v dan težje dosegljive. Pri odločitvah o dispozicijah izdelanih šarž se vse pogosteje sprašujemo, kaj vemo o »škodljivcih« v jeklu, kdaj, kako in v kakšnih količinah so tako imenovani oligoelementi sploh škodljivi? Kje so meje, ki jih lahko še dopuščamo? Vse kaže, da so se raziskovalci na tem področju utrudili ali pa so ob nerešenih problemih postali malodušni. Odgovorov na postavljena vprašanja še ni! Današnji način dela in tehnološke značilnosti pa vse bolj neodložljivo terjajo jasne in nedvoumne odločitve.

Oligoelementi baker, kositer, antimon in arzen imajo manjšo afiniteto do kisika, kot jo ima železo, zato večji del vsebnosti teh elementov, ki pridejo z vložkom v jeklarsko peč, v jeklu tudi ostane. Težave z učinkovitim prebiranjem starega železa povzročajo, da vsebnost oligoelementov v jeklu narašča, posebno še s kroženjem staro železo — vložek.

V zvezi z omenjeno afiniteto do kisika selektivna oksidacija površine izrine oligoelemente iz škaje in močno poveča njihovo koncentracijo v površinskem sloju jekla. Pri določenih pogojih ogrevanja se elementi koncentrirajo po kristalnih mejah avstenita. To povzroči zmanjšanje trdnosti zveze med kristalnimi zrni avstenita in nastanek medkristalnih razpok v začetku valjanja. To pokvari površino valjanca in vodi k izmečku.

Slika 1 kaže primer take obogatitve mej avstenitnih zrn, kjer prihaja celo do staljenih evtektikov. Meritve na elektronskem mikroanalizatorju so v tem primeru raziskave, izvršene na Metalurškem inštitutu v Ljubljani[11], pokazale vzdolž kristalnih mej nad 90 % bakra, do 2 % niklja, do 1,25 % arzena, do 0,55 % antimona in do 3,8 % kositra. V drugih primerih[1] je Vodopivec ugotovil sestave 60 % Cu, 30 % Sn in 45 % Cu, 28 % Sn, 20 % Sb. Nastala tekoča faza ima po njegovih meritvah tališče pod 700 °C in po literaturnih podatkih veliko omočljivost. Zato se vrine v notranjost jekla po avstenitnih mejah, oslabi njihovo kohe-

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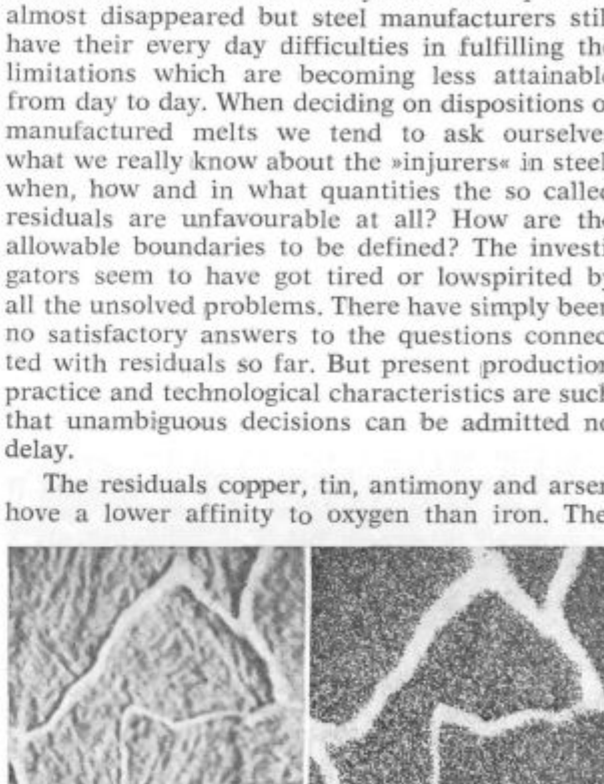
INTRODUCTION

Some twenty years ago discussions on residuals seemed to be very fashionable in technical references. In the last few years this topic has almost disappeared but steel manufacturers still have their every day difficulties in fulfilling the limitations which are becoming less attainable from day to day. When deciding on dispositions of manufactured melts we tend to ask ourselves what we really know about the »injurers« in steel, when, how and in what quantities the so called residuals are unfavourable at all? How are the allowable boundaries to be defined? The investigators seem to have got tired or lowspirited by all the unsolved problems. There have simply been no satisfactory answers to the questions connected with residuals so far. But present production practice and technological characteristics are such that unambiguous decisions can be admitted no delay.

The residuals copper, tin, antimony and arsen hove a lower affinity to oxygen than iron. The-



Slika 1

Obogatitev oligoelementov po mejah avstenitnih zrn zaradi selektivne oksidacije (F. Vodopivec)

Fig. 1

Enrichment of austenitic grain boundaries with trace elements due to selective oxidation (F. Vodopivec)

zijo in povzroča raztrganine pri preoblikovanju. V že omenjenem delu sta Rekar in Brifah ugotovila, da naraščanje vsebnosti bakra, arzena in antimona povečuje gostoto in velikost površinskih razpok pri vročem upogibu. Intenziteta trganja površine pa se še poveča pri binarnih ali ternarnih kombinacijah, pri čemer je vpliv antimona mnogo večji od vpliva arzena. Maksimum pokljivosti je pri 1100 °C.

Razumljivo je, da ima površinski sloj, ki ima drugačno sestavo kot jeklo, tudi drugačne preoblikovalne lastnosti. Na tem področju so bile izvršene zelo številne raziskave, ki so pokazale, da se pri oblikovanju obogatene plasti različni elementi različno obnašajo. Sistematične preiskave so pokazale, da pri selektivni oksidaciji arzen, antimon in kositer oblikujejo zvezni obogateni sloj z enakomerno debelino, če so v jeklu sami ali v kombinaciji. V primeru, da vsebuje jeklo tudi baker, pride do prerazdelitve elementov in spremembe oblike obogatenega sloja. Arzen se ohrani v enakomernem sloju, nad njim pa se v fazi, ki je bogata z bakrom, zbereta skoraj ves antimon in kositer.

BAKER

Baker je lahko v jeklu namerno dodan legirni element za izboljšanje odpornosti proti koroziji v naravnih atmosferah ali za doseganje nekaterih magnetnih in drugih fizikalnih lastnosti jekel. To področje prisotnosti bakra v jeklu ni predmet te obravnave, ki je namenjena spoznavanju vplivov nenamerno prisotnega bakra — oligoelementa v jeklu.

Količina bakra v jeklu med 0,20 in 0,30 % je pri današnji tehnologiji izdelave jekla že povsem normalna. Manj bakra v jeklu dosegamo le s skrbno izbiro vložka in s posebnimi tehnološkimi postopki v proizvodnji. Posamezne taline z nad 0,50 % bakra niso nobena redkost. Prav ta dejstva postavljajo vprašanje bakra v ospredje tako pri reševanju vsakodnevne proizvodne problematike, kot tudi pri številnih raziskovalnih temah.

Že dolgo je poznan vpliv bakra na predelavnost jekla in nastanek površinskih napak. Poznana je lomljivost v rdečem zaradi bakra, površinske raztrganine in posebne oblike krokodilove kože.

Baker vpliva tudi na mehanske in nekatere druge pomembne lastnosti jekla, ki so odločilnega pomena za uporabo.

Znano je tudi, da je vpliv bakra in drugih prisotnih oligoelementov več kot le aditiven.

Povsem naravna je želja jeklarjev in uporabnikov jekla, da bi mogli določiti največjo dopustno količino bakra v splošnem, ali za določene posebne primere. To je zelo kompleksno vprašanje in prav gotovo bo želja po jasnem odgovoru, brez številnih omejitev veljavnosti, še dolgo ostala neizpolnjena.

refore the most part of their contents arriving into the furnace by batch, remain in steel. Troubles with efficient scrap iron sorting cause increase of residuals content in steel, especially because of scrap iron — batch circulation.

In connection with the already mentioned relation of the oxygen affinity the selective surface oxydation displaces the residuals from the scale and strongly increases their concentration under the surface layer of the steel. At definite heating conditions the elements are concentrated on austenite grain boundaries. The connection between crystal grains is therefore weakened and in initial rolling the intercrystalline cracks appear. This spoils the rolled product surface and causes troubles.

Figure 1 shows an example of such enrichment on austenite grain boundaries where even molten eutectic appear. Measurements on electron microanalyser, carried out in the Institute of Metallurgy in Ljubljana[11] showed over 90 % Cu, to 2 % Ni, to 1.25 % As, to 0.55 % Sb and to 3.8 % Sn along crystal boundaries. In other cases[1] Vodopivec found compositions of 60 % Cu — 30 % Sn and 45 % Cu — 28 % Sn — 20 % Sb. According to his measurements the melting point of the molten phase is below 700 °C and according to reference it shows considerably great wettability. Therefore it interpolates along the crystal boundaries of austenite, weakens their cohesion and causes tearings during deformation. In the paper, already referred to, Rekar and Brifah found out that increase in copper, antimony and arsen contents increases the density and size of surface cracks in hot bending. In binary and ternary combinations the surface cracking is even more intense, whereby the influence of antimony is far stronger than that of arsen. The maximum crackability is found at 1100 °C.

It is clear that the surface layer having different composition than steel also shows different deformation properties. Numerous investigations carried out in this field showed that in forming the enriched layer different elements behave differently. Sistematic research showed that in selective oxidation the residuals arsen, antimony and tin form a continuous enriched layer with regular thickness when they appear in steel separately or in combination. In case that steel also contains copper, the elements are redistributed and the form of the enriched layer is changed. Arsen is saved in a regular layer, practically all antimony and tin gather in a phase over this layer which is rich with copper.

COPPER

Copper is an alloying element which can be deliberately added to improve resistance to corrosion in natural atmospheres or to obtain some magnetic and other physical properties of steel.

Po binarnem Fe-Cu sistemu[6] je topnost bakra v gama železu pri 850 °C 4 % in pri 1094 °C 8 %. Torej bo baker kot oligoelement vedno v trdni raztopini, četudi prisotnost nekaterih drugih elementov zelo zmanjša njegovo topnost.

Največja topnost bakra v feritu je pri 850 °C in znaša 1,4 %, a se že okrog 700 ° zmanjša na ca. 0,4 %, pri sobni temperaturi pa v glavnem ne presega 0,2 %. Kveder[6] potrjuje ugotovitve drugih raziskovalcev, da se nekatere lastnosti jekel začno bistveno spreminjati prav pri vsebnosti 0,4 % Cu, in s tem opozarja na zvezo med vplivom na lastnosti in topnostjo v feritu.

Vpliv bakra na pokljivost površine je dobro raziskan in v tem pogledu so si mnenja dokaj enotna, tako da so nekako definirane maksimalne dopustne količine bakra v jeklu, posebno v povezavi s kositrom. Na drugi strani pa so mnenja o vplivu bakra na lastnosti jekel tako heterogena, da skoraj ni mogoče dati kakih zaključkov dosedanjih raziskav. Ob številnih publikacijah in zelo revnih ugotovitvah se vsiljujejo pomisleki o pomanjkljivi usmerjenosti in sistematičnosti doslej opravljenih raziskav, ki so vsekakor zelo razdrobljene na parcialne probleme, iz katerih zaradi spremljajočih vplivov ni mogoče graditi kompleksnih zaključkov.

Kveder[6] povzema iz literature nekoliko podrobneje naslednje pomembnejše ugotovitve:

— Silver[6.1] trdi, da se začne izražati neugoden vpliv bakra na kakovost površine jekla pri vroči predelavi že pri 0,2 % Cu, posebno ob prisotnosti 0,010 do 0,015 % Sn. Za predelavo jekla v litem stanju, kar je seveda najpomembnejše glede na poznane probleme začetka vroče predelave, postavlja Pejčoch[6.2] to vsebnost bakra in kositra kot največjo dovoljeno. Povečanje kositra na 0,02 že pri 0,15 % bakra hudo poslabša predelovalnost jekla.

— Na osnovi preizkušanja klinastih valjarniških vzorcev dovoljuje Pejčoch[6.2] pri navadnih konstrukcijskih jeklih največjo količino bakra 0,45 %. Že ob prisotnosti 0,02 % Sn se kritična deformacija močno zmanjša, zato je v tem primeru tudi dovoljena vsebnost bakra znatno manjša.

— V zvezi s prisotnostjo bakra je najbolj kritično temperaturno področje 1150—1200 °C.

— Zaradi več kot aditivnih vplivov kombinacije Cu in Sn je iz literature poznana omejitev po Melfordu[6.3]

$Cu + 8\,Sn \leq 0,4$ s tem, da je razmerje $Cu/Sn > 4$

Kasneje je Melford ta empirijski izraz razširil s tem, da je enako upošteval vpliv kositra in antimona, obenem pa je uvedel nov faktor E — indeks obogatitve. Temu faktorju je Vodopivec oporekal veljavnost[1]; ugotovil je namreč, da se zbira talina iz bakra, kositra in antimona v drobnih kapljicah med škajo in jeklom ter ustvarja velike lokalne obogatitve, ki dosegajo 100 in več od povprečne sestave.

The range of copper presence in steel is no topic of this paper which is meant to recognize the influence of undeliberately present copper as a residual.

Copper content between 0.20 and 0.30 % is quite normal in classic technology of steel manufacturing. A lower copper content in steel can only be achieved by careful batch sampling and by special technological production cycles. Individual heats containing over 0.50 % Cu are not extraordinary anymore. These facts have pushed the problem of Cu content in the foreground in solving the everyday production problems as well as in numerous investigations.

The copper influence on deformability of steel and surface defects has been known for a long time. Brittleness in red caused by copper, surface tearings and special forms of crocodile skin are also known.

Copper also influences mechanical and other important steel properties what is of decisive significance for steel application.

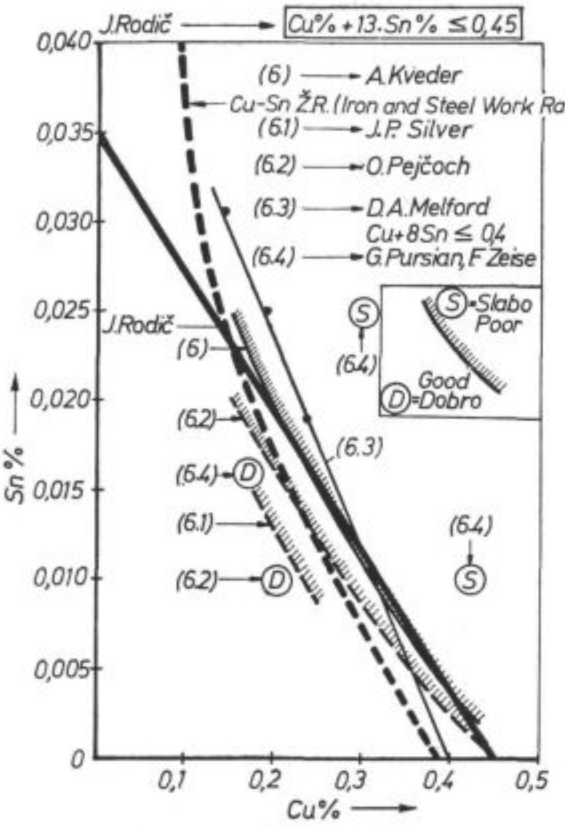
It is also known that the influence of copper and other residuals is more than merely additive.

The wish of steel manufacturers and users who would like to be able to define the highest allowable copper content in general or for some special cases, is quite natural. This wish of a clear answer without numerous validity limitations represents a complex problem and it cannot be expected to be fulfilled in near future.

In binary Fe-Cu system[6] the solubility of Cu in gama iron at 850 °C amounts to 4 %, at 1094 °C it amounts to 8 %. Therefore copper as a residual will always be found in solid solution although its solubility is considerably lowered by presence of some other elements.

The highest solubility of copper in ferrite is at 850 °C amounting to 1.4 %. At 700 °C it decreases to approximately 0.4 %, and at ambient temperatures it doesn't exceed 0.2 % on the whole. Kveder[6] confirms the investigations of some other authors that some steel properties begin to change expressively right at the copper content of 0.4 % and calls our attention to the connection between the influence on properties and solubility in ferrite.

The copper influence on surface cracking has been accurately investigated. The opinions are quite uniform so that it is possible to define the maximum allowable copper contents in steel, especially when connected with tin. The findings about copper influence on steel properties on the other hand are so heterogeneous that it is impossible to draw some general conclusions from the results of the previous research work. Although numerous papers on this topic have been published, the findings have been rather unsatisfactory, thus causing doubts about orientation and systematics of the previous research work being cut into partial problems allowing no complex conclusions to be drawn.



Slika 2

Območje dobre in slabe sposobnosti za vročo predelavo po podatkih iz literature in lastnih ugotovitvah glede na razmerje vsebnosti Cu : Sn (J. Rodič)

Fig. 2

Good/poor warm workability ranges according to Cu : Sn relations (J. Rodič)

— Pursian in Zeise[6.4] sta ugotovila pojavljanje površinske pokljivosti pri kovanju, če je bilo v jeklu več kot 0,3 % Cu, še posebno ob prisotnosti več kot 0,025 % Sn (slika 2). Baker v količinah do 0,3 % po mnogih ugotovitvah v literaturi ne vpliva na lastnosti.

Vir 1 navaja Stephensonovo ugotovitev, da se Melfordovi rezultati dobro ujemajo z ameriškimi izkušnjami. Gotovo je, da je veljava Melfordovega kriterija odvisna ne samo od količine oligoelementov, temveč tudi od specifičnosti pogojev livne in predelovalne tehnologije za jeklene bloke, pa tudi od proizvodnega programa. Zato smo se odločili, da preverimo, kako je uporaben v razmerah železarne Ravne.

Upoštevajoč razpoložljive literaturne vire in lastne ugotovitve statističnih obdelav 10-letne dokumentacije, bi bila s poenostavitvijo medsebojnega vpliva na linearno regresijo najprimernejša omejitev

$$Cu\,\% + 13\,Sn\% \leq 0{,}45$$

Stephenson navaja, da v jeklu z 0,15 % C povečanje kositra od 0,002 do 0,056 % zmanjša deformacijsko sposobnost pri vroči torziji na polovico. Podobno velja za jekla z 0,45 do 1 % C, vendar je

Referring to various reference sources Kveder[6] resumes the following important findings:

— Silver[6.1] maintains that the unfavourable influence of copper on steel surface quality in hot deformation begins already at 0.2 % Cu, especially if 0.010 to 0.015 % Sn is present. Pejčoch[6.2] believes that these Cu and Sn contents are the highest allowable in steel forming after casting. According to the known problems that could be met with in the initial state of hot deformation the steel deformability after casting is most important. The increase of Sn content to 0.02 % badly influences deformability already at 0.15 % Cu.

— On the basis of wedge form rolling mill sample testing Pejčoch[6.2] declares that the highest allowable copper content in normal structural steel grades is at 0.45 %. If 0.02 % Sn is present, the critical deformation is strongly weakened, so the allowable copper content in this case must also be considerably lower.

— The most critical temperature range connected with copper presence lies between 1150 and 1200 °C.

— As a result of more than merily additive influence of Cu and Sn combination, Melford's limitation[6.3] is known:

$$Cu + 8\,Sn \leq 0{,}4$$
$$\text{with } Cu/Sn > 4$$

Melford completed later his empirical limitation considering an equal influence of antimony and tin and introducing a new factor, E — the index of enrichment. Vodopivec exprimed doubts about the real significance of this index noting that the melt rich in copper, tin and antimony gathered in droplets at the scale steel interface. High local enrichments are formed and the content of residuals could reach values as high as a few hundred times more than the average content in steel.

— Pursian and Zeisse[6.4] found surface brittleness during forging of steel grades containing more than 0.3 % Cu, especially when more than 0.025 % Sn was present (Fig. 2). According to the references copper content of up to 0.3 % has no influence on steel properties.

Stephenson, quoted in ref. (1), states that Melford observations agree with the general experience in USA. It is clear that the validity of the Melford criterium depends not only on the content of residuals in steel, but also from his composition as well as from the casting and hot working of steel blocks. It has been decided therefore to check how the Melford limitation could be applied in the Ravne Steelworks.

Considering the available reference as well as our own statistical data processing over a period of 10 years, and simplifying the reciprocal influence on linear regression, the most appropriate limitation would be:

$$Cu\,\% + 13\,Sn\% \leq 0{,}45$$

preoblikovalna sposobnost jekel zadostna za normalno valjanje tudi še pri 0,30 % Sn. Ta vsebnost pa je daleč nad ugotovljeno vsebnostjo kositra v naših jeklih.

ARZEN, ANTIMON IN KOSITER

Arzen, antimon in kositer so močno topni v feritu in manj v avstenitu. Kažejo močno nagnjenost k dendritskemu strjevanju in pospešujejo sekundarno trakavost jekla.

Antimon povečuje nagnjenost k popustni krhkosti, torej tudi k staranju, zato ker zmanjšuje topnost ogljika v feritu. Podoben vpliv na lastnosti jekla ima kositer. Gabrovšek je ugotovil, da kositer poveča nagnjenost jekla k staranju in da dodatek aluminija njegov škodljiv učinek odpravi.

Iz raziskav na Metalurškem inštitutu v Ljubljani[1] je mogoče sklepati, da kositer nima neugodnega učinka na plastičnost jekla pri počasni deformaciji, nasprotno pa močno zniža žilavost, tako v staranem kot v nestaranem stanju. V zelo široko zastavljenem delu sta Rekar in Brifar opredelila učinek bakra, antimona in arzena v različnih kombinacijah na mehanske in tehnološke lastnosti jekla. V grobem lahko iz tega dela povzemamo naslednje ugotovitve:

— Obravnavani oligoelementi ne vplivajo na raztržno trdnost in razteznost v normaliziranem stanju;

— baker znižuje prehodno temperaturo žilavi — krhki lom;

— arzen je brez učinka na prehodno temperaturo žilavi — krhki lom;

— antimon to prehodno temperaturo izrazito poviša.

Za legirana jekla ni na voljo podatkov, na osnovi katerih bi mogli opredeliti učinek kositra. Domnevamo, da povečuje kaljivost in zniža žilavost jekla ter poviša prehodno temperaturo, vendar ni enotnosti o tem, kolikšen je njegov učinek. Kaže, da prisotnost molibdena v jeklu odpravi škodljivi učinek kositra na žilavost, vendar ti rezultati niso bili potrjeni.

Moremo torej sklepati, da baker in arzen v množinah, ki jih sedaj najdemo v naših jeklih, nimata zaznavnega učinka na statične in dinamične lastnosti malooglljičnih jekel. Povišanje količine antimona in kositra bi lahko kmalu imelo za posledico znižanje zarezne žilavosti jekel. Problematična je opredelitev količine, do katere sta ta dva elementa neškodljiva. V dosedanjih raziskavah so bile često razlike med posameznimi šaržami zaradi drugih vzrokov tolikšne, da so presegle učinek dodanih oligoelementov.

BIZMUT

je razmeroma malo raziskan. V jeklih je njegova vsebnost reda velikosti desettisočink odstotka. Povzroča krhkost in močno poslabša plastičnost v vročem[2].

According to Stephenson, an increase of Sn content from 0.002 to 0.056 % in a steel grade with 0.15 % C lessens the deformability at hot torsion to half the value. In steel grade containing 0.45 % to 1 % C the situation is the same though deformability of steels for normal rolling is satisfactory even at 0.30 % Sn. This Sn content highly exceeds Sn content in our steel grades.

ARSEN, ANTIMONY AND TIN

Arsen, antimony and tin are highly soluble in ferrite and less soluble in austenite. They strongly incline to dendrite solidification and enhance the secondary banded structure.

Antimony increases the inclination to temper brittleness and consequently also to ageing decreasing the carbon solubility in ferrite. Tin has similar influence on steel properties. Gabrovšek found out that tin increases the inclination to ageing and that its unfavourable effect can be minimized by aluminium addition.

From the research work carried out in the Institute of Metallurgy in Ljubljana[1] the conclusion can be drawn that tin doesn't show unfavourable influence on the plasticity of steel in slow deformation but on the other hand it strongly reduces toughness in aged as well as in not aged condition. In a very broadly stated research, Rekar and Brifah have defined the influence of copper, antimony and arsen in different combinations on mechanical and technological properties of steel. The following findings can be drawn from their research:

— The discussed residuals have no influence on tensile strength and alongation of the steel in normalized condition.

— Copper decreases the transition temperature.

— Arsen has no influence on transition temperature.

— Antimony considerably increases the transition temperature.

There are no data for alloyed steels on the basis of which tin influence could be defined. It is supposed to increase hardenability and to decrease toughness as well as to increase the transition temperature. But there are no uniform opinions as to how expressive its effect is. The molibdenum presence in steel seems to minimize the unfavourable tin influence on toughness but these results haven't been confirmed yet.

Therefore it can be concluded that the copper and arsen contents which are presently found in our steel grades, can have no perceiving influence on static and dynamic properties of low carbon steels. Increased antimony and tin contents could quickly result in a lower notch toughness. Deter-

SVINEC

povzroča med kovanjem in valjanjem razpoke ob robu ingotov. Izloča se vzdolž primarnih zrn in med dendritnimi kristali[2].

MOLIBDEN IN VOLFRAM

povečujeta kaljivost, zmanjšata raztezek in poslabšata preoblikovalno sposobnost v vročem, predvsem pri avstenitnih jeklih zaradi tvorbe ferita.

KOBALT

ima majhen vpliv. Njegova prisotnost je nedopustna samo v nerjavnih jeklih za jedrsko tehniko, zato se tam največkrat zahteva omejitev maks. 0,01 % Co.

NIOB

kot oligoelement močno povišuje mejo plastičnosti.

CINK

v jeklarskem procesu izpari, ker ima visok parni tlak.

VSEBNOST BAKRA V ELEKTRO JEKLU

Podatki o povprečni vsebnosti bakra v elektro jeklu Slovenskih železarn dokaj dobro sovpadajo, če upoštevamo strukturo asortimentov v proizvodnih programih.

Slika 3

Statistična analiza vsebnosti bakra v različnih vrstah jekel (J. Rodič)

Fig. 3

Statistical analyses of copper content in diverse steel grades (J. Rodič)

mination of the contents up to which these two elements have no unfavourable influence, is very problematic. In the previous research the differences between individual melts were often so great that they exceeded the influence of the added residuals.

BIZMUT

hasn't been accurately researched yet. Its content of order of magnitude in steel is ten thousandth percent. It causes brittleness and strongly reduces plasticity in hot[2].

LEAD

causes cracks on ingot edges during forging and rolling. It is precipitated along primary grains and among dendrites[2].

MOLIBDENUM AND TUNGSTEN

increase hardenability, reduce elongation and hot deformability especially in austenitic steels because ferrite is formed.

COBALT

possesses minimal influence. Its presence is unallowable only in stainless steels for nuclear technique, the demanded limitation there is max. 0.01 % Co.

NIOB

as residual strongly increases the yield point.

ZINC

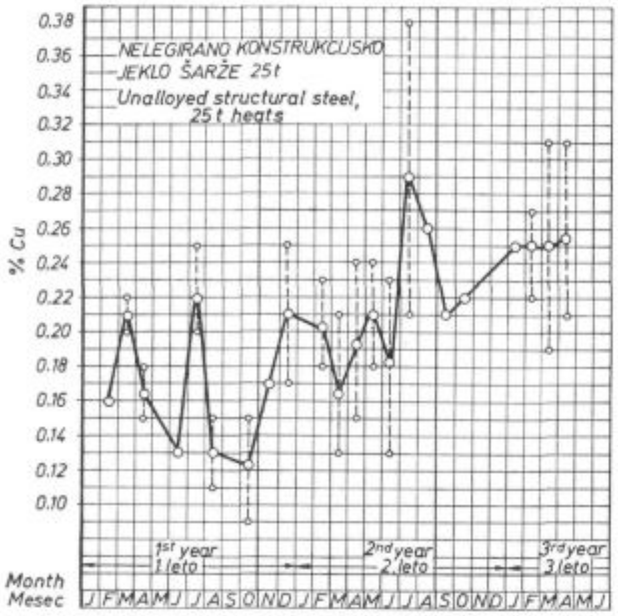
having a high vapour pressure evaporates in steel manufacturing process.

COPPER CONTENT IN ELECTRIC STEEL

Considering the various assortiments of production programs in Slovene iron works, the data of average copper content in electric steel are quite uniform.

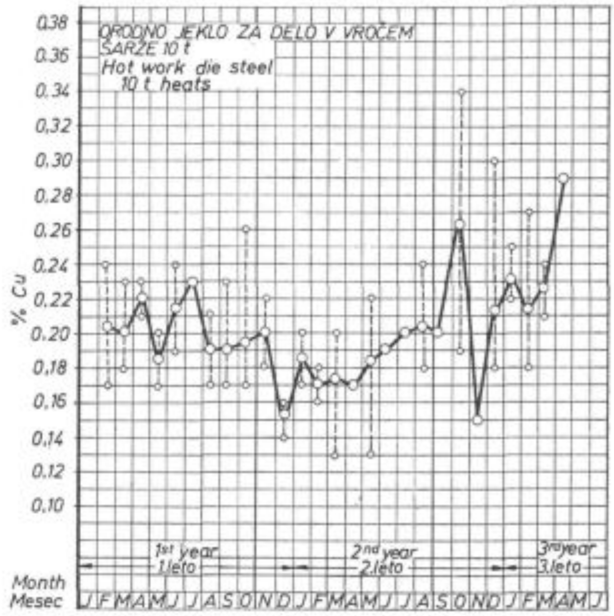
Figure 3 represents a resume of copper content from the Ravne Steelworks documentation[3, 4, 5] in characteristic steel groups for a period of ten years. The general average is about 0.2 % Cu, only in high alloyed steels and by special batch sampling an average content of less than 0.18 % Cu could be expected. Copper content of less than 0.25 % cannot be guaranteed in the present production conditions. In the group No. 5 the copper content in structural steels manufactured from a specially purchased batch — scrap iron with a guaranteed low copper content, is shown.

Because of the technological characteristics and batch circulation an increase of copper content in steel must be expected. This general tendency is shown by two examples in Figures 4 and 5 in the form of statistical control charts $\bar{x}$-R for individual months over a period of three successive



Slika 4
Statistična kontrolna karta za vsebnost bakra v jeklih z nizko vsebnostjo ogljika (J. Rodič)

Fig. 4
Statistical control chart for copper content in low carbon steel grades (J. Rodič)



Slika 5
Statistična kontrolna karta za vsebnost bakra v orodnem jeklu za delo v vročem (J. Rodič)

Fig. 5
Statistical control chart for copper content in hot work die steel grade (J. Rodič)

Slika 3 prikazuje povzetek vsebnosti bakra v jeklu iz dokumentacije železarne Ravne[3, 4, 5] za desetletno obdobje po značilnih skupinah jekel. Splošno povprečje je okrog 0,2 % Cu, le pri visoko legiranih jeklih in ob posebni izbiri vložka lahko pričakujemo povprečno vsebnost pod 0,18 % Cu. Vsebnost bakra pod 0,25 % v danih pogojih proizvodnje ni mogoče več zagotoviti. Pri skupini št. 5 je prikazana vsebnost bakra v konstrukcijskih jeklih, izdelanih iz posebej nabavljenega vložka — starega železa z zagotovljeno nizko vsebnostjo bakra.

Ob tehnoloških značilnostih je zaradi kroženja vložka treba pričakovati naraščanje vsebnosti bakra v jeklu. Ta splošna tendenca je za obdobja treh zaporednih let prikazana z dvema primeroma na slikah 4 in 5 v obliki statističnih kontrolnih $\bar{x}$-R kart po mesecih. Očitno je veliko nihanje vsebnosti bakra, kar je ob znanih problemih nabave vložka iz različnih izvorov povsem razumljivo. Nujno potrebno bo skrbeti za pomlajevanje vložka, pri čemer bo pomembna tudi uporaba železove gobe.

VSEBNOSTI DRUGIH OLIGOELEMENTOV

Vsebnosti kositra precej nihajo, kar pripisujemo vplivu izvora starega železa za vložek (slika 6).

Srednje vrednosti[7] nihajo od 0,011 do 0,027 % Sn, največje vsebnosti pa od 0,020 do 0,045 % Sn.

To so ugotovitve statistične analize 8787 šarž za devetletno obdobje[4, 7] s 95 % statistično zanesljivostjo.

years. A great copper content oscillation is obvious which is quite understandable considering the known problems connected with purchasing from different sources. Greater care will have to be payed to batch tappering with a special respect to iron sponge.

CONTENTS OF OTHER RESIDUALS

Tin content oscillate a great deal due to the influence the origin of scrap iron has on the batch (Fig. 6).

Medium value oscillate[7] from 0.011 to 0.027 % Sn, and the highest content from 0.020 to 0.045 % Sn.

These findings were obtained by a statistic analysis of 8787 metls carried out in a period of two years[4, 7] with a statistical probability of 95 %.

In guaranteed pure scrap iron separately purchased for batch, the average Sn content of 0.006 % was found.

Arsen contents are in all steel groups practically the same, the scattering is considerably low. It was observed in 8774 melts in the 0.024 to 0.032 % As range for a period of nine years[4, 7]. No considerably lower As contents were observed in guaranteed pure scrap iron, separately purchased for a batch.

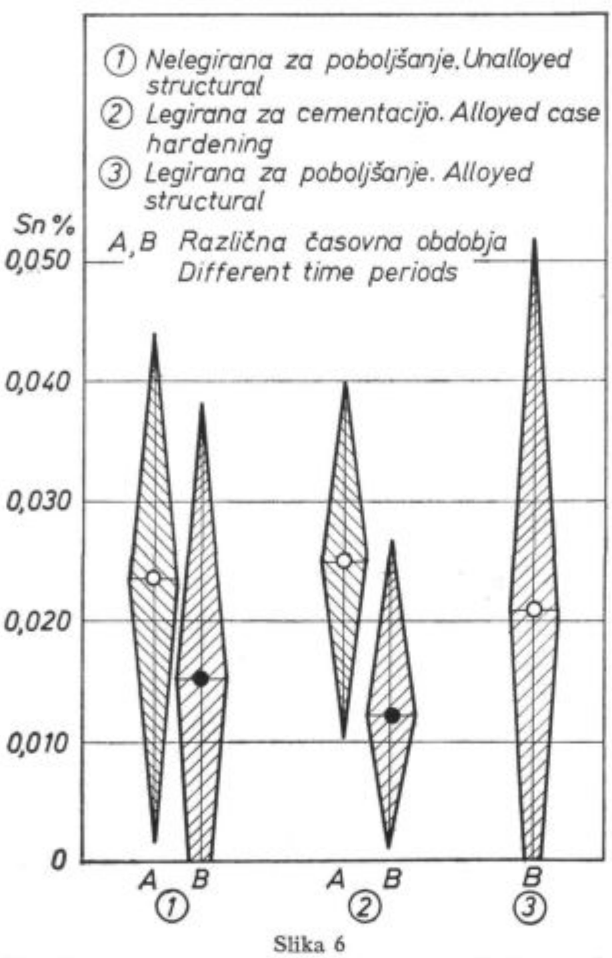
There are only few data available for antimony content. These contents vary in the range of 0.003 to 0.012 % with almost no regard to steel grades — from unalloyed to stainless and tool steels.

Pri posebej nabavljenem zagotovljeno čistem starem železu za vložek smo ugotovili povprečno vsebnost 0,006 % Sn.

Vsebnosti arzena so pri vseh skupinah jekel zelo enake in trosenje je razmeroma majhno, za 8774 šarž v območju 0,024 do 0,032 % As za devetletno obdobje[4, 7]. Tudi pri posebej nabavljenem zagotovljeno čistem starem železu za vložek nismo ugotovili bistveno nižje vsebnosti arzena.

Za vsebnost antimona v jeklu imamo razmeroma malo podatkov. Skoraj ne glede na vrsto jekla, od nelegiranih do nerjavnih in orodnih, so vsebnosti v območju 0,003 do 0,012 % Sb.

Do neke mere problematična postaja že vsebnost niklja kot oligoelementa. V nelegiranih konstrukcijskih jeklih smo ugotovili v dveh letih pri 3388 šaržah povprečno vsebnost 0,06 % Ni, pri malo legiranih konstrukcijskih jeklih pri 1625 šaržah povprečno vsebnost 0,10 % Ni, pri orodnih jeklih za hladno delo povprečno 0,15 % Ni in pri orodnih jeklih za vroče delo 0,18 % Ni. Le pri ogljikovih orodnih jeklih s skrbno izbiro vložka in kontrolo dispozicij po prvi analizi še držimo povprečno vsebnost niklja pod 0,05 %.



Slika 6

Statistična analiza vsebnosti kositra v različnih vrstah jekla

Fig. 6

Statistical analyses of tin content in diverse steel grades

There are some problems represented by Ni contents. In unalloyed structural steels an average Ni content of 0.06 % was observed in 3388 melts in two years while in low alloyed structural steels the average Ni content in 1625 melts was 0.10 %. In tool steels for cold and hot work the average Ni content was 0.15 % and 0.18 %, respectively.

Only in carbon tool steels with very careful batch sampling and disposition control an average Ni content of less than 0.05 % after the first testing can be obtained.

Similar situation was found for Cr content being a steel polluting element. In unalloyed structural steels an average Cr content of even about 0.15 % was found with the extreme contents approaching 0.30 % Cr thus causing a lot of difficulties already after the first testing. The Cr content is essentially lower only in the carbon tool steels but in the regular production practice it is almost impossible to expect a deliberately manufactured melt with a satisfactory guaranteed shallow hardenability of the extra-special quality gradation. A melt with such characteristics ought to be specially sampled in the present situation.

INVESTIGATIONS

In the »Slovenske železarne« a coordinated program for the residuals influence investigation was accepted in the year 1975. The coordination of the research work was entrusted to the Institute of the Metallurgy in Ljubljana with the following goals:

— to define the highest concentrations of residuals in individual steel grades when steel can still be hot worked without faults having at the same time all the prescibed properties,

— to define the interval of the highest influence of residuals on hot deformability and to find out whether the unfavourable influence could be minimized by means of simple technological steps.

On the whole we restricted ourselves to the research of copper and tin influence, these two elements being most frequent in steel and having the most unfavourable effect on deformability because of enrichment under the scale.

Copper increases the tensile strength and yield point and decreases the elongation.

With higher copper content the precipitation hardening is considerably effective, the hardness increases.

In investigating the hot work die steel UTOP Mo 1 (W. Nr. 2343) with an increased copper content of 0.45 % no special unfavourable influences on properties tested in the quality control and considered essential for the quality determination of this steel could be found.

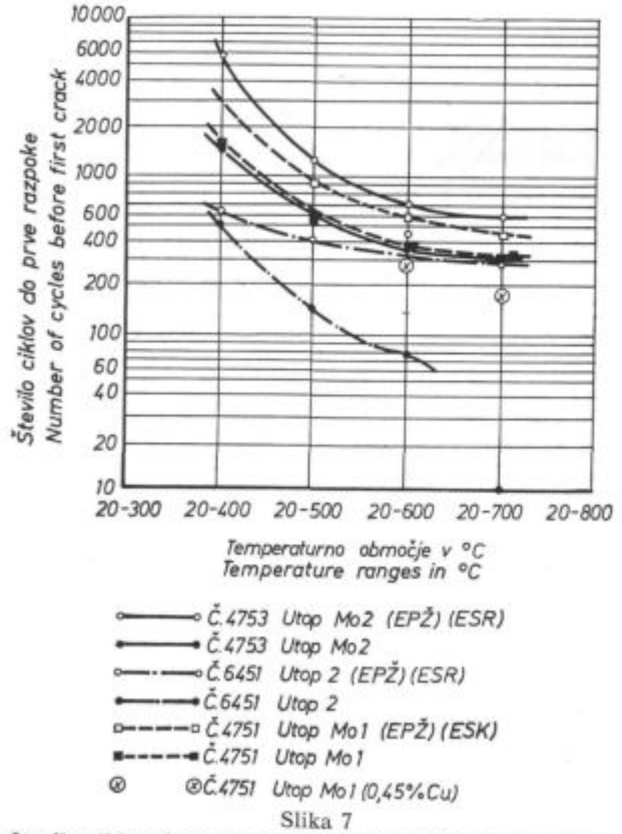
Podobno je ugotovljeno stanje pri vsebnosti kroma kot onesnaževalca jekla. Pri nelegiranih konstrukcijskih jeklih je povprečna vsebnost kar okrog 0,15 % Cr, ekstremne vsebnosti pa se približujejo celo 0,30 % Cr, kar povzroča že po prvi jeklarski analizi nemalo težav. Tudi vsebnost kroma je le pri ogljikovih orodnih jeklih občutno nižja, vendar je v redni proizvodnji že skoraj nemogoče pričakovati namensko izdelano šaržo z zadovoljivo plitko kaljivostjo kakovostne gradacije exstra — special. Šaržo s takimi specialnimi karakteristikami je treba v današnji situaciji posebej izbirati.

RAZISKAVE

Slovenske železarne so v letih 1975-76 sprejele usklajen program raziskav za spoznavanje vplivov oligoelementov. Metalurškemu inštitutu so poverile povezovanje vseh raziskovalnih nalog z naslednjimi cilji:

— opredelitvi največje koncentracije oligoelementov za posamične vrste jekel, da se jeklo še predeluje v vročem brez napak in ima pri tem predpisane lastnosti;

— opredeliti za tipične vrste jekel interval najmočnejšega vpliva oligoelementov na preoblikovalnost v vročem in preveriti, ali se škodljivi uči-

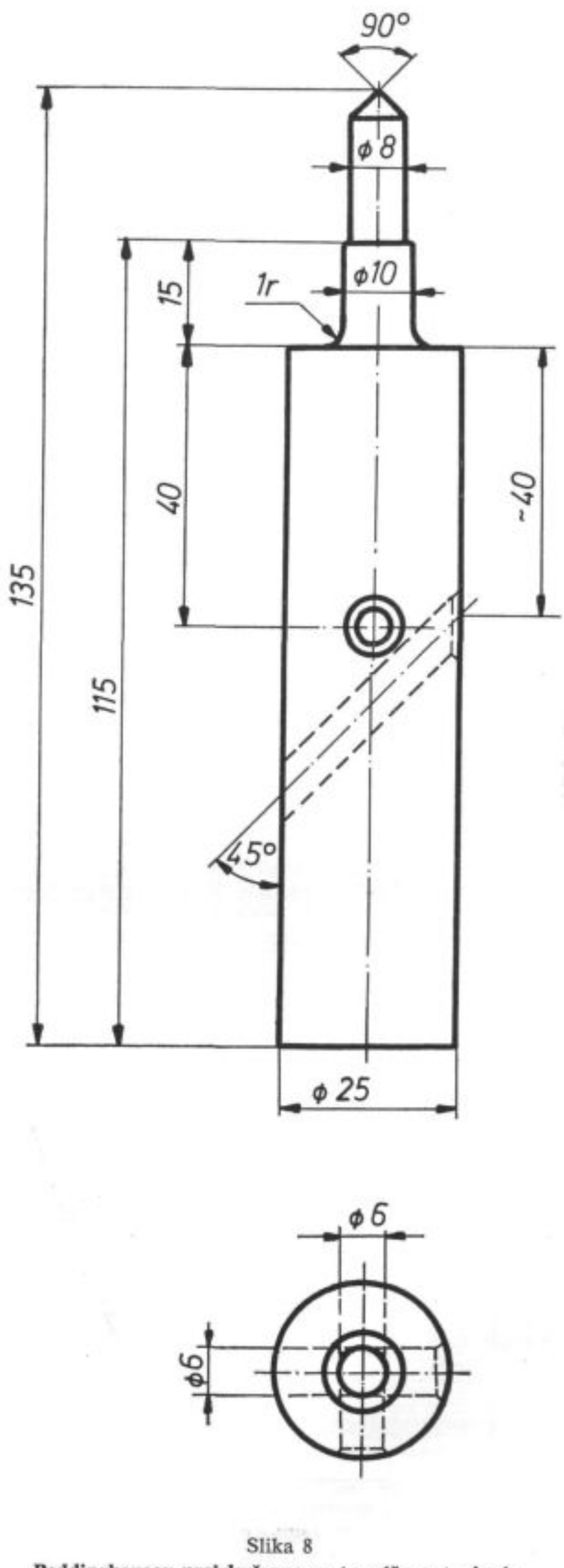


Slika 7

Število ciklov do prve razpoke za specifična temperaturna območja (A. Kveder, M. Švajger, F. Černe)

Fig. 7

Number of cycles before first crack in specific temperature ranges (A. Kveder, M. Švajger, F. Černe)



Slika 8

Peddinghausov preizkušanec za termično utrujanje

Fig. 8

Peddinghaus — type testing sample

nek da zmanjšati z enostavnimi tehnološkimi ukrepi.

V glavnem smo se omejili na raziskovanje učinka bakra in kositra, ki sta v jeklu najbolj pogosta in glede predelovalnosti najbolj škodljiva zaradi obogatitve pod škajo.

Baker povečuje natezno trdnost in mejo plastičnosti, zmanjšuje pa raztezek.

Pri večji vsebnosti bakra je precej učinkovita izločilna utrditev, poveča se trdota.

Pri raziskavah orodnega jekla za vroče delo UTOP Mo 1 (W. Nr. 2343) s povišano vsebnostjo bakra 0,45 % Cu v železarni Ravne nismo mogli ugotoviti posebnih kvarnih vplivov na lastnosti, ki jih v kontroli kakovosti preizkušamo in jih smatramo kot odločilne za oceno kakovosti tega orodnega jekla[8].

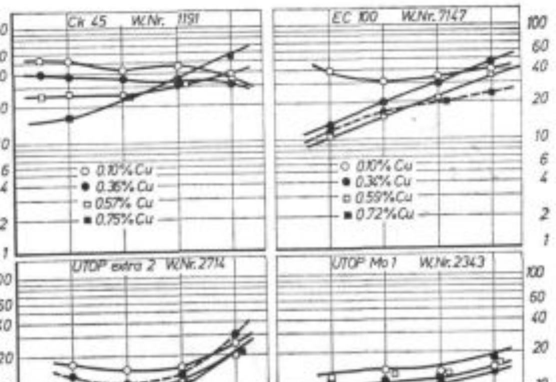
Le s preizkusom termičnega utrujanja, ki po naših izkušnjah dokaj dobro karakterizira obnašanje tega jekla pri delu v vročem, smo ugotovili, da baker zmanjšuje odpornost proti termičnemu utrujanju (slika 7).

Za preizkušanje termičnega utrujanja smo uporabljali preizkušance, prikazane na sliki 8, ogrevane in ohlajene z avtomatsko krmiljenimi ciklusi na ustrezno adaptirani Peddinghausovi napravi[8].

Primerjava preizkušancev jekla UTOP Mo 1 (W. Nr. 2343) iz dveh šarž z različno vsebnostjo bakra 0,27 % in 0,45 %:

— S preizkušanjem torzije v vročem v temperaturnem območju od 800 do 1300 °C nismo ugotovili med preizkušanci obeh šarž nobene pomembne razlike v številu zasukov N in maksimalnem momentu M_{max}.

— Pri preizkušanju udarne žilavosti DVM preizkušancev, izrezanih iz enakih palic vzdolžno in prečno, smo ugotovili s primerjavo obeh šarž, da



Slika 9
Primerjava rezultatov preizkušanja s torzijo v vročem (A. Kveder)

Fig. 9
Comparative warm torsion testing (A. Kveder)

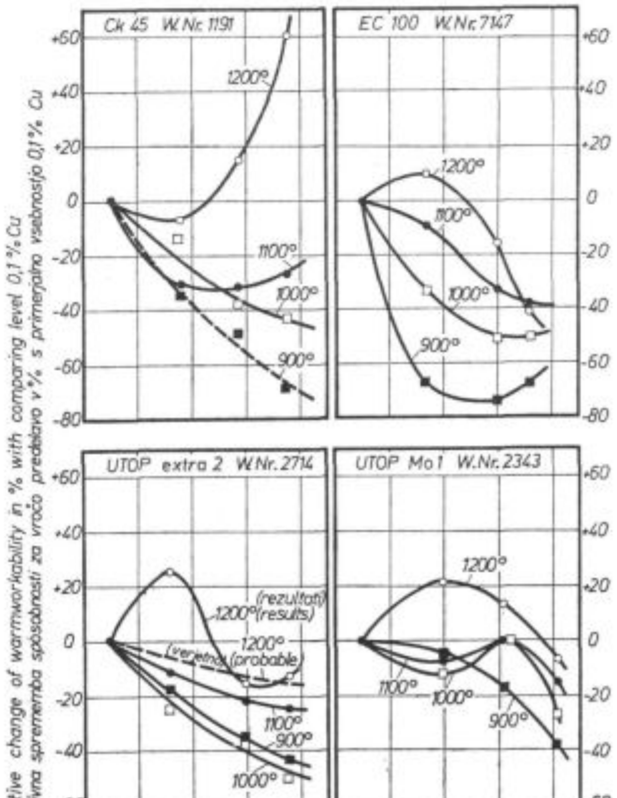
Only with thermal fatique test, which we believe characterizes the behaviour of this steel grade in hot working quite well, increased copper content considerably lowers the resistance to thermal fatique from those generally known for this steel grade (Fig. 7).

For the thermal fatigue test the test pieces shown in Fig. 8 were used, heated and cooled by automatically steered cycles on an adapted Peddinghaus installation.

Comparison of steel samples UTOP MO 1 (W. Nr. 2343) from two melts with 0.27 % Cu and 0.45 % Cu:

— With hot torsion test no important difference in the measured numbers of rotations N and maximum moment M_{max} was observed in the temperature range from 800 to 1300 °C.

— For the notch toughness test DVM samples were cut out from equal bars longitudinally and transversely. In comparing the two melts we found out that the samples from the melt with a higher copper content showed to 1 HRC higher hardness. The average longitudinal toughness was



Slika 10
Relativna sposobnost za vročo predelavo štirih različnih vrst jekel v odvisnosti od vsebnosti bakra (A. Kveder)

Fig. 10
Relative warmworkability of four different steel grades influenced by copper contents (A. Kveder).

je bila pri šarži z višjo vsebnostjo bakra trdota preizkušancev do 1 HRC večja, vzdolžna žilavost povprečno za vse različno toplotno obdelane preizkušance za 11 % boljša in prečna žilavost za 20—60 % slabša.

— Pri preizkušanju žilavosti po posebni metodi železarne Ravne za orodna jekla je bila povprečna žilavost obeh šarž za celotno območje variacij toplotne obdelave skoraj enaka.

Pri kovanju ingotov teže 4 t ni bilo v redni proizvodnji nobenih razlik in sta se obe šarži kovali povsem normalno.

Da bi preverili te ugotovitve, smo opravili serijo sistematičnih laboratorijskih raziskav na metalurškem inštitutu v Ljubljani[6]

— za pet reprezentantnih vrst jekel,

— za štiri gradacije bakra v območju od 0,1 do 1,0 % Cu v istih matičnih talinah.

Rezultate preizkušanja torzije v vročem kaže slika 9.

Pri jeklu Ck 45 je neugoden vpliv bakra očiten pri temperaturah do 1000 °C, nad 1100 °C se ta vpliv zmanjša in pri 1200 °C postane prisotnost bakra celo ugodna.

Pri jeklu EC 100 je neugoden vpliv bakra precej bolj očiten in se izraža že pri vsebnosti ca. 0,3 %.

Pri jeklu Utop extra 2 je vpliv bakra podoben kot pri Ck 45, vendar nekoliko manj izrazit.

Pri jeklu Utop Mo 1 je vpliv bakra najmanj izrazit, kar do neke mere potrjuje prejšnje ugotovitve, zaradi katerih smo to nalogo načrtovali.

Slika 10 še bolj nazorno kaže rezultate teh raziskav za primerjave[6].

V celoti je Kveder[6] ugotovil, da baker negativno vpliva na predelovalnost preizkušanih jekel in jo poslabša tudi do 70 %, vendar pa se v nobenem primeru ni predelovalnost toliko zmanjšala, da bi jeklo ne bilo več predelovalno. Odločilno vlogo pa ima lahko to zmanjšanje predelovalnosti v povezavi z drugimi oligoelementi in pri obogatenju le-teh pod škajo. Pri višjih temperaturah vpliva bakra ni več opaziti ali pa je celo pozitiven.

Pri raziskavah vpliva bakra na mehanske lastnosti smo ugotovili:

— da baker ne vpliva bistveno na raztezek in kontrakcijo;

— pri Ck 45 baker poveča trdnost in mejo plastičnosti, pri EC 100 pa ju močno zmanjša, medtem ko je vpliv bakra pri orodnih jeklih za delo v vročem manj izrazit. Ta vpliv je mnogo bolj jasno izražen v žarjenem stanju kot v poboljšanem, zato v tem pogledu vplivu bakra ne pripisujemo posebnega pomena;

— pri preizkušanju žilavosti ISO — V (J) smo dobili presenetljive rezultate[6]. Absolutne vrednosti žilavosti so zelo različne in večinoma izredno visoke (slika 11).

for all differently heat treated samples by 11 % higher, whereas the transversal toughness was lower by 20—60 %.

In toughness tests with a method developed for tool steels in »Železarna Ravne« the average toughness was practically equal for a whole range of the heat treatment variations.

There were no differences in the normal production forging of 4 t ingots, both melts were forged quite normally.

To verify these findings a series of sistematic laboratory tests were carried out in the Institute of Metallurgy in Ljubljana[6]

— for five representative steel grades

— for four copper gradations in the range from 0.1 to 1.0 % Cu in the same parent melt.

Figure 9 shows results of hot torsion tests.

In carbon structural steel Ck 45 the unfavourable copper influence becomes expressive at temperatures up to 1000 °C. Over 1100 °C this influence is lowered and at 1200 °C the copper presence becomes even favourable.

In case hardening low alloy steel grade EC 100 the unfavourable copper influence is considerably more obvious, becoming expressive already at contents of ca. 0.3 %.

In the hot work die steel UTOP extra 2 copper has similar yet somehow less expressive influence than in Ck 45.

In the hot work die steel UTOP Mo 1 the copper influence is the least expressive thus confirming the previous findings because of which this research work was planned.

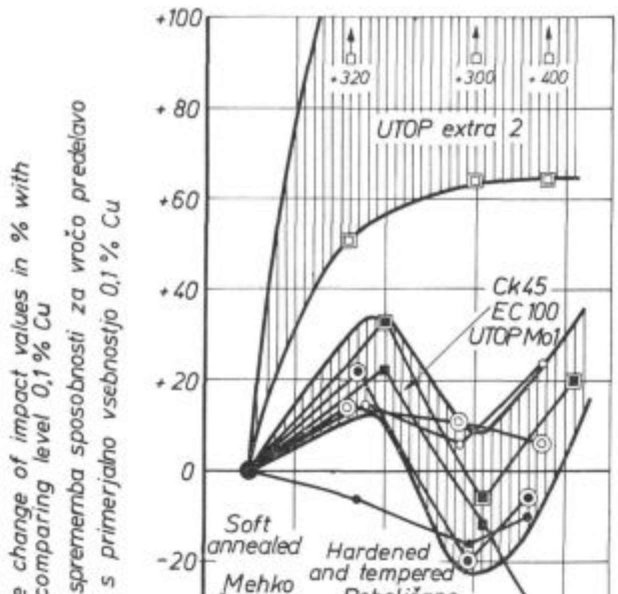
The results of these investigations are even more clearly shown in Figure 10[6].

On the whole Kveder[6] found out that copper unfavourably influences the deformability of the tested steels decreasing it even by 70 %. In no case however the deformability was decreased to such an extent that the steel wouldn't be workable anymore. The decreased deformability is of essential importance in connection with other residuals and in their enrichment under the scale. At higher temperatures the copper influence isn't observed anymore or it even has a positive character.

In investigating the copper influence on mechanical properties the following findings were observed:

— Copper shows no essential influence on elongation and reduction of area.

— In Ck 45 copper increases hardness and yield point, in EC 100 it reduces them strongly, whereas its influence in tool stels for hot working is less expressive. It is far more evidently expressed after annealing than after hardening and tempering therefore the copper influence isn't considered to be important here.



Slika 11

Žilavost različnih vrst jekla v odvisnosti od različnih vsebnosti bakra (A, Kveder)

Fig. 11

Impact values of different steel grades influenced by copper content (A. Kveder).

Slika 11 kaže Utop extra 2 kot izreden primer, ker baker izboljša žilavost vse do 0,8 % Cu. Pri ostalih treh vrstah jekel so razlike manjše. Kaže, da pri teh povečanje bakra do okoli 0,35 % izboljša žilavost, nadaljnje povečanje vsebnosti bakra pa do okoli 0,60 % žilavost poslabša, nakar se le-ta pri nadaljnjem zviševanju bakra ponovno izboljšuje. Pri 0,8 % Cu je povprečna žilavost še vedno tako dobra kot pri 0,1 % Cu. Zanimivo je, da se prav pri vsebnosti okoli maksimalne topnosti bakra, tj. ca. 0,35 % Cu trend odvisnosti spremeni.

Prelomi žilavostnih preizkušancev so zelo žilavi.

Domnevamo, da so ti pojavi povezani s topnostjo, oziroma z izločanjem bakra[6]. V temperaturnem območju izvajanih toplotnih obdelav je topnost Cu v feritu okoli 0,35 %. Pri nižjih temperaturah se topnost zmanjšuje in znaša pri sobni temperaturi pod 0,2 %. Baker v trdni raztopini (do 0,35 %) povečuje trdnost in izboljša žilavost jekla. Če ga je v jeklu več kot 0,35 %, bo del bakra ostal izločen. Trdnost in meja plastičnosti se bosta ustalila, na žilavost pa ti izločki vplivajo negativno. Podrobnejša Kvedrova hipotetična razlaga[6] je zanimiva, vendar ne razloži vseh odvisnosti, ki smo

— In toughness test ISO-V (J) surprising results were obtained[6]. Absolute toughness values are very different and mostly extraordinary high (Fig. 11).

Figure 11 shows UTOP extra 2 as a special example with copper increasing the toughness by up to 0.8 % Cu. In the remaining three steel grades the differences are smaller. The copper content of up to approximately 0.35 % seems to improve the toughness in them. By further increase of copper content to about 0.60 % the tougness is lowered and by still further increase improved again. At 0.8 % Cu the average toughness is still so good as at 0.1 % Cu. It is interesting that the trend of dependency changes at the contents around maximum copper solubility, that is at ca. 0.35 % Cu.

Fractures of test pieces show high toughness.

These phenomena are considered to be connected with copper solubility and with copper precipitation respectively[6]. In the temperature range of the performed heat treatments Cu solubility in ferrite was about 0.35 %. At lower temperatures the solubility is reduced, at ambient temperature it is less than 0.2 %. In solid solution copper (to 0.35 %) increases hardness and improves toughness. When more than 0.35 % Cu is present in steel, one part of it will remain precipitated. Hardness and yield point will stabilize. These precipitations unfavourably influence toughness. Detailed Kveder's hypothetic interpretation is interesting, but it does not explain all dependency. In alloyed hot work die steels the copper influence on hardness and yield point is largely covered by carbide precipitation processes. The phenomenon that more than 0.6 % Cu improves toughness again is hardly to explain.

Torkar, Vodopivec and Arh[9] carried out interesting investigations of residuals influence on deformability of the cast steel surface. On the basis of the previous research work a new method of quantitative deformability testing was developed enabling more reliable determination of the residuals influence on brittleness. This method is important for the hot rolling practice.

After the surface is transformed, the coarse cast texture along the surface collapses thus changing the steel deformability there. Such a step lowered the brittleness of steels which are alluminium killed thus having high Al and N contents. This idea promising to decrease brittleness by simple technological steps was to be laboratory tested and verified in the course of industrial production.

Brittleness was quantitatively determined by counting and measuring cracks on tensile side of bended samples.

An increase in the amount of tin results in increased number of cracks, while increase in jih ugotovili. Pri utopnih legiranih jeklih je verjetno vpliv Cu na trdnost in mejo plastičnosti precej prekrit s karbidnimi izločilnimi procesi. Tudi pojav, da več kot 0,6 % Cu ponovno izboljša žilavost, je težko razložiti.

Zanimive raziskave na področju spoznavanja vplivov oligoelementov na preoblikovalno sposobnost površine litega jekla so opravili Torkar, Vodopivec in Arh[9]. Na osnovi ugotovitev pri raziskavah prejšnjih let so razvili novo metodo za kvantitativno preizkušanje preoblikovalne sposobnosti, ki omogoča večjo zanesljivost ocenjevanja vplivov oligoelementov na pokljivost. Ta metodika preizkušanja je pomembna za prakso vročega valjanja.

Ko se izvrši prekristalizacija površine, se poruši groba lita tekstura ob površini in se spremeni deformacijska sposobnost jekla ob površini. Tak ukrep je zmanjšal pokljivost jekel, ki so pomirjena z aluminijem in imajo nadpovprečno vsebnost aluminija in dušika. V tem je bila raziskovalna ideja, ki jo je bilo treba laboratorijsko raziskati, ker obeta enostavne tehnološke ukrepe za zmanjšanje pokljivosti, in te ukrepe nato na osnovi raziskovalnih rezultatov tudi v industrijski proizvodnji preveriti.

Pri tej metodi so avtorji pokljivost kvantitativno ovrednotili s tem, da so na natezni strani upognjenih preizkušancev prešteli in izmerili razpoke.

Naraščanje količine kositra povečuje število razpok, naraščanje količine bakra pa njihovo dolžino. Podaljšanje ogrevanja povzroča povečanje dolžine in števila razpok. Razlike v pokljivosti zaradi sestave in temperature avtorji razlagajo z razliko v velikosti zrn avstenita pri temperaturi deformacije in različnega prodiranja bakra in kositra po mejah avstenitnih zrn.

Bistveno drugačna je površina deformiranih vzorcev, ki so bili ogreti po prejšnji prekristalizaciji z ohladitvijo na sobno temperaturo. Na prekristaliziranem jeklu se pojavijo podobne razpoke pri približno 0,80 % bakra, kot na neprekristaliziranem jeklu s približno petkrat manj bakra.

Laboratorijske raziskovalne ugotovitve so avtorji verificirali tudi v industrijskih pogojih z ogrevanjem in valjanjem dveh 4-tonskih blokov z vsebnostjo 0,89 % bakra in 0,032 % kositra, od katerih so enega po vlivanju ohladili do temne površine. Blok, ki je bil vroče založen, je imel številne grobe površinske napake, medtem ko se je prekristalizirani blok, to je po vlivanju ohlajeni blok, izvaljal skoraj brez napak. Ta ukrep za zmanjšanje vpliva visoke vsebnosti oligoelementov na preoblikovalnost površine jekla je tehnološko enostaven in zelo učinkovit.

Vpliv bakra in kositra na deformacijsko sposobnost površine jekla po selektivni oksidaciji površine je najbolj izrazit pri temperaturi okoli 1150 °C.

copper increases the length of cracks. Longer heating results in the increase of both length and number of cracks. Differences in brittleness due to composition and temperature are explained by different austenite grain size at deformation temperature and by copper and tin penetrating along austenite grain boundaries.

Surface of the deformed samples, heated after transformation and cooled to the ambient temperature, is essentially different. In transformed steel similar cracks are found at approximately 0.80 % Cu as those found in unrecrystallized steel with approximately five times lower Cu content.

Laboratory results were tested in industrial conditions by heating and rolling of two 4 t — ingots with 0.89 % Cu and 0.032 % Sn, one of them being cooled to dark surface after casting. The hot charged ingot showed numerous coarse surface defects whereas the transformed ingot cooled after casting was rolled out without faults. This method to minimize the influence of high residuals content on the steel surface deformability is technologically simple and very efficient.

The copper and tin influence on the steel surface deformability after selective surface oxidation is most expressive at a temperature about 1150 °C.

CONCLUSION

Residuals, their contents and influences on steel properties were sufficiently recognized from various reference sources and numerous investigations carried out in »Železarna Ravne«. Considering the known circumstances no important differences in the residuals content, especially no trend towards lowering the content of residuals could be expected. It is recommendable to further investigate the residual influences on steel properties and to look for efficient technological measures to prevent or to minimize the worst consequences taking into account the known residual content that cannot be changed anymore. It is here that efficient steps to minimize cobble and missed production can be expected.

The surface cracks are known to be connected with scale forming during heating and therefore with furnace conditions. We cannot expect that the scaling intensity in forging and rolling mill heart type furnaces could be essentially influenced on. Perhaps it will be possible to introduce in near future proceedings to protect the steel surface during heating. These methods are presently known but they haven't been applied in production practice yet. An important and practically applicable method is surface cleaning in the course of technological process as it must always be kept in mind that only the steel surface has low deformability.

ZAKLJUČKI

Iz obsežne literature in številnih lastnih raziskav smo oligoelemente, njihove vsebnosti in vplive na lastnosti jekla zadovoljivo spoznali. Ob znanih okoliščinah ni pričakovati pomembnih sprememb vsebnosti oligoelementov v jeklih, posebno pa ni pričakovati trenda zniževanja le-teh. Bolj priporočljivo je z raziskavami nadalje spoznavati vplive oligoelementov na lastnosti in iskati učinkovite tehnološke ukrepe za preprečevanje ali zmanjšanje najhujših posledic ob ugotovljenih vsebnostih oligoelementov, ki jih ne moremo več spremeniti. V tej smeri lahko pričakujemo uspešne ukrepe za zmanjševanje izmečka in neuspele proizvodnje.

Danes vemo, da je pojav raztrganin na površini pri vroči predelavi vezan na nastanek škaje pri ogrevanju, in torej na razmere v peči. Malo je verjetno, da bi se dalo v kovaških in valjarskih ogrevnih pečeh bistveno vplivati na intenziteto škajanja. Morda bo v bližnji bodočnosti mogoče v industrijsko prakso uvajati postopke, ki so danes poznani, a v praksi še neuporabljani, za zaščito površine jekla pri ogrevanju s premazi in emajli. Pomemben in praktično uporaben ukrep je pa seveda čiščenje v toku tehnološkega procesa, saj se moramo vseskozi zavedati, da ima slabo preoblikovalno sposobnost le površinski sloj jekla.

Prekristalizacija, dosežena z ohlajanjem in ponovnim ogrevanjem je danes že dokazan in večkrat v praksi preverjen ukrep za izboljšanje preoblikovalne sposobnosti problematičnega jekla. To je najenostavnejši postopek, za katerega pa se zaradi stroškov s porabo energije in časa le težko odločimo. Če bomo znali kvantitativno in zanesljivo opredeliti tveganje za nastanek izmečka, pa bomo našli prav v tem, sicer dragem postopku, velike prihranke z reševanjem kritičnih primerov.

Te ugotovitve so še posebej pomembne ob ugotovljenem dejstvu, da sedanje povprečne količine oligoelementov — te že povzročajo težave pri vroči predelavi — še ne predstavljajo splošne kritične nevarnosti za lastnosti jekel, razen določenih izjem in nekaterih še vedno odprtih pomembnih vprašanj.

V kolikor je izpolnjen pogoj

$$Cu\,\% + 13\,.\,Sn\,\% \leq 0{,}45,$$

lahko pričakujemo dobro preoblikovalno sposobnost pri normalnih pogojih vroče plastične predelave.

Mnogo jekel se dobavlja z zagotovljeno žilavostjo. Vemo, da antimon in kositer znižujeta žilavost in povišujeta prehodno temperaturo. Gotovo bi bilo zelo koristno ugotoviti, od katere najmanjše vsebnosti je pričakovati pomemben učinek obeh elementov na žilavost, posebno tedaj, ko se jeklo dobavlja z žilavostjo, ki je zagotovljena pri nizki temperaturi. Vprašanje je tudi, kako prisotnost antimona in kositra v takih jeklih vpliva na žilavost varov. Potrebno bi bilo tudi ugotoviti, kolikšen je vpliv alfagenih oligoelementov na intenzi-

Today transformation achieved by cooling and repeated heating is a proved and by practice affirmed method to improve deformability of problematic steel grades. Though the simplest method, it is rather expensive and not often applicable because of high energy consumption and time required. If we develop a reliable way for quantitative determination of cobble risk, this otherwise expensive method will make considerable cost savings possible.

These findings are especially important considering the fact that the average residual amounts today — already causing difficulties in heat treatment — represent no general critical danger for steel properties though there are some exceptions and still unsolved questions.

When the condition

$$Cu\,\% + 13\,.\,Sn\,\% \leq 0{,}45,$$

is fulfilled, good deformability at normal conditions of warm working can be expected.

A lot of steel grades are supplied with guaranteed toughness. Antimony and tin are known to lower the toughness and increase the transition temperature. It would be very useful to find out the lowest content from which on important influence of both elements on toughness could be expected, especially when steel is supplied with guaranteed toughness at low temperatures. The question is how antimony and tin influence the toughness of weldings in such steels. Further the influence of alfagene residuals on the secondary banded structure is to be investigated. Finally the influence of alfagenic residuals on delta ferrite formation and its stabilisation is to be found out. This problem is connected with perspective manufacturing of stainless steel grades and welding electrode stainless materials.

There are very few data referring to alloyed steels and influence of residuals on the deformation course and morphology as well as on formation of microstructure and steel properties after hardening and tempering. This field shouldn't be neglected in further research as a great part of the Slovene steel production includes steel grades determined for heat treatment.

This paper has no intention to state any special or even the latest findings in the field of residuals. It merely represents a survey of our activity of the last few years in solving the most urgent problems by research work. It was our intention to show what we presently know about residuals and their influences and how we attend to their content. We also wanted to show the way we tried to explain their influence on steel properties and on steel behaviour during deformation as well as in application by means of deliberate investigations and research work more or less connected with production practice and control.

teto sekundarne trakavosti. Dalje se nam zdi potrebno, da se razčisti vprašanje, ki je pomembno v zvezi s perspektivno proizvodnjo nerjavnega jekla in dodajnega nerjavnega materiala, kako alfageni oligoelementi vplivajo na pojav delta ferita in njegovo stabilizacijo.

V literaturi je na voljo najmanj podatkov o legiranih jeklih in o vplivu oligoelementov na potek in morfologijo transformacije ter na izoblikovanje mikrostrukture in lastnosti jekla po kaljenju in popuščanju. Tudi to področje ne bi smelo ostati zanemarjeno pri bodočih raziskavah, saj velik del slovenske jeklarske proizvodnje obsega prav jekla, ki so namenjena za toplotno obdelavo.

Ta članek ne predstavlja nekih posebnih najnovejših raziskovalnih dosežkov na področju oligoelementov, ampak podaja le pregled dejavnosti Slovenskih železarn v zadnjem obdobju za reševanje najnujnejših problemov v zvezi z raziskavami. Naš namen je bil prikazati, kaj pri nas o oligoelementih in njihovih vplivih danes vemo, kako njihovo vsebnost spremljamo in kako smo z namenskimi preiskavami in raziskavami, vezanimi bolj ali manj na tekočo proizvodnjo in kontrolo, skušali pojasniti njihov vpliv na lastnosti in obnašanje jekel v predelavi in uporabi.

Navrgli smo nekaj vprašanj in tudi smernic za nadaljevanje teh prizadevanj, proizvodna praksa in raziskave naslednjega obdobja pa naj pokažejo, koliko so problemi res aktualni in kateri so najpomembnejši.

Some problems together with orientation for further research were put forward. Production practice and future investigations will show whether these problems are really actual and which are the most important.

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