O vplivu bakra in kositra na vročo krhkost litega konstrukcijskega jekla z 0,12 % C in 1,2 % Mn

On the influence of copper and tin on the hot shortness of as cast structural steel with 0.12 % C and 1.2 % Mn

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A. UVOD

Z vplivom oligoelementov na preoblikovalnost jekel smo se ukvarjali že v preteklosti[1] in pojasnili njihovo obnašanje v obpovršinski plasti jekla med škajanjem. Pokazala se je potreba, da bi vpliv oligoelementov na preoblikovalnost opredelili v selektivnejši obliki ter preverili in dopolnili merila o vplivu njihove množine na preoblikovalnost z upoštevanjem lite strukture jekla. Omejili smo se na obravnavo učinka bakra in kositra, ki sta najbolj pogosta v jeklih in s stališča predelavnosti najbolj škodljiva zaradi obogatitve pod škajo.

B. NAMEN DELA

Postopek industrijskega ogrevanja jekla pred vročim valjanjem ne nudi veliko možnosti, da bi odpravili selektivno oksidacijo, ki je naravna posledica nastajanja škaje pri ogrevanju jekla. Debelino in sestavo škaje je mogoče spreminjati s spremembo atmosfere in temperature v peči, vendar to ne vpliva zaznavno na selektivno oksidacijo. Ta izrine iz škaje elemente, ki imajo manjšo prosto energijo tvorbe oksidov kot železo in jih bogati v kovini pod škajo. Dosedanje raziskave[2, 3, 4, 5] kažejo, da je vpliv oligoelementov na preoblikovalno sposobnost najbolj izrazit pri jeklu, ogretem pred vročo deformacijo na 1150 °C (sl. 1).

Če ingote in brame pred zalaganjem na ogrevanje za valjanje ohladimo do temperature, ko se izvrši prekristalizacija površine, se poruši groba lita struktura ob površini in izboljša deformacijska sposobnost jekla ob površini. Tak ukrep zmanjša vročo krhkost jekla z 0,16 % ogljika in 1,2 % mangana ter nadpovprečno vsebnostjo aluminija in dušika[6].

Zanimalo nas je, ali ta sprememba v načinu ogrevanja vpliva tudi na pokljivost v vročem, ki je posledica oligoelementov.

C. EKSPERIMENTALNO DELO

Odločili smo se, da uporabimo za preizkuse modificirano metodo[7] vročega upogiba po Bornu[8] in Melfordu[9], vendar z uporabo litih vzorcev, kot

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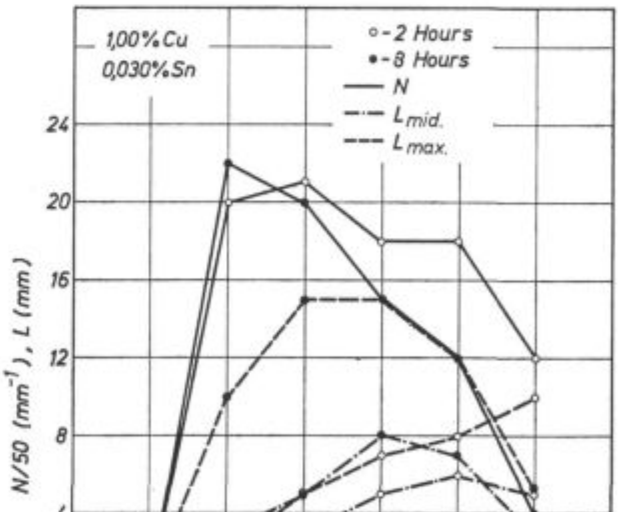
A. INTRODUCTION

In a previous work[1] the influence of residuals on the workability of steel was investigated and an explanation for their behaviour in the subscale layer of steel was proposed. However, a more selective determination of the influence of residuals on the hot workability was required considering the structure of as cast steel. The present investigation has been limited to the influence of copper and tin since they are most frequently found in steel and because of their enrichment in subscale layer which results in a very harmful influence on the workability of steel.

B. AIM

The heating proces before hot rolling does not offer great possibilities to avoid the selective oxidation which is a natural consequence of scaling. The thickness and the composition of



Slika 1

Odvisnost med temperaturo, številom (N), maks. dolžino (L_{max}) in povprečno dolžino (L_{mid}) razpok na površini jekla pri upogibu po 2 in 8 urah ogrevanja.

Fig. 1

The relationship between temperature, number (N), max. length (L_{max}) and the midle length (L_{mid}) of cracks on bent steel surface after 2 and 8 hrs heating.

je predložil Schmitz[10] z 20 % natezno deformacijo. Najprej smo s poizkusi preverili uporabnost metode in njeno selektivnost pri različnih sestavah jekel in pri različnih temperaturah ogrevanja pred vročo deformacijo.

Preizkuse smo nato nadaljevali pri konstantni temperaturi 1150 °C, pri kateri se je v predhodnih preizkusih pokazal največji negativni vpliv oligoelementov.

Površinske napake, ki nastajajo pri ohlajanju, segrevanju in predelavi blokov, so pogosto vezane na kristalizacijsko strukturo jekla. Večja vsebnost oligoelementov, bakra, kositra, antimona ali aluminija in dušika zmanjšuje duktilnost jekla v prvi fazi valjanja ali kovanja. Izkušnje iz industrije kažejo, da je jeklo veliko bolj občutljivo na pojav razpok pri valjanju ingotov, kot pri valjanju gredic iz istega jekla, kljub temu da je temperatura ogrevanja pred valjanjem podobna. Do sedaj še ni splošno zadovoljive teorije, ki bi pojasnjevala nezadostno duktilnost površine. Vzrok teh nejasnosti je v tem, da so bile vse preiskave duktilnosti jekla izvršene na vzorcih, ki so bili že predhodno predelani in temperaturno transformirani. Zato je bila struktura preiskovanih jekel drugačna kot je struktura, ki nastane pri kristalizaciji jekla v blokih. Iz tega sledi, da metodika preizkušanja preoblikovalnosti, ki ne zajema vpliva transformacije, ne more biti ustrezna za postavljanje realnih zaključkov o preoblikovalnosti jekla v blokih z lito strukturo[11]. Zato je metoda, ki upošteva tudi strukturo kristalizacije, bistveno primernejša za ugotavljanje porekla in vzrokov površinskih napak na površini blokov med prvimi prehodi skozi valje.

Zahtevi po ohranitvi kristalizacijske strukture je mogoče ustreči z modifikacijo metode vročega upogibanja, pri kateri se vroče upogibajo vzorci z lito strukturo.

S kvantitativnim ovrednotenjem napak na upognjeni površini je mogoče opredeliti objektivne parametre za interpretacijo različnih faktorjev na vročo krhkost površine bloka.

Deformabilnost smo kvantificirali tako, da smo na konveksni strani vzorca prešteli razpoke in izmerili nihovo dolžino.

1. Sestava jekel

Za preiskave smo uporabili osnovno jeklo z 0,12 % ogljika in 1,2 % mangana, ki je znano kot zelo občutljivo na pojav razpok pri vroči deformaciji. Osnovni sestavi smo dodali od 0,15 do 0,85 % bakra in 0.011 do 0,050 % kositra (tabela 1). Ta interval pokriva količine oligoelementov, ki jih običajno najdemo v jeklih. Preiskave smo izvršili na litih vzrocih, ki so bili pred zalaganjem na ogrevanje ohlajeni — prekristalizirani, ali založeni vroče in brez prekristalizacije.

scale can be controlled by changing the temperature and the gas composition of furnace atmosphere, however these means have no significant effect on selective oxidation. The elements of lower free energy of formation of oxides as compared to iron are expelled out of scale and enriched in the surface layer of steel beneath the scale.

Earlier investigations[2, 3, 4, 5] showed that the harmful influence of residuals on the workability of steel is most pronounced in steel heated to 1150 °C before the hot deformation (fig. 1).

The hot workability of ingot surface is significantly improved if ingots are cooled under the austenite transformation temperature in order to modify the as cast structure of ingot surface and then heated to rolling temperature. This practice was used to improve the hot workability of 0,16 C, 1,2 Mn steel with aluminium and nitrogen content in excess of the average values[6]. It was interesting to find out whether the transformation influences the hot shortness caused by the presence of residuals also.

C. EXPERIMENTAL

Modified[7] hot bending tests according to Born[8] and Melford[9] with as cast samples as proposed by Schmitz[10] and 20 % of stretching were applied. The applicability and selectivity of the method was verified by preliminary tests carried out on steels of different composition and heated at different temperatures before the deformation. After the preliminary trials all hot deformation tests were carried out at the same temperature 1150 °C since the harmfull influence of residuals is the strongest at this temperature.

Surface defects which occur at cooling, heating and rolling of ingots are often associated with the solidification structure of steel. Increased amount of copper, tin, antimony or aluminium and nitrogen decrease hot ductility in the first passes of rolling or forging. Industrial experience has shown that steel is much more sensitive to surface cracking when rolling ingots as compared to billets despite similar rolling temperature.

The reason why it was frequently difficult to explain poor hot workability of steel surface is in the fact that ductility tests have been performed on samples which have previously endured transformation, i. e. the structure of steel was not the same as that of as cast ingots. Consequently, the workability tests which do not account for the transformation are not suitable and therefore can not be used for a reliable determination of hot workability of as cast steel[11]. Only the workability tests which take into account the actual structure make it possible to determine the causes for surface cracking of ingots at the start of hot working.

Tabela 1: Sestava jekel
Table 1: Steel composition

Vzorec Sample	C	Si	Mn	Cu	Sn	Sb
11 H 11 V	0,07	0,59	1,18	0,15	0,011	0,005
12 H 12 V	0,06	0,45	1,03	0,16	0,024	0,005
21 H 21 V	0,12	0,57	1,15	0,18	0,019	0,005
22 H 22 V	0,11	0,51	1,08	0,15	0,048	0,006
31 H 31 V	0,11	0,58	1,15	0,23	0,010	0,006
32 H 32 V	0,11	0,56	1,13	0,25	0,024	0,005
41 H 41 V	0,12	0,59	1,22	0,25	0,033	0,005
42 H 42 V	0,11	0,56	1,16	0,24	0,050	0,004
51 H 51 V	0,09	0,63	1,26	0,45	0,017	0,005
52 H 52 V	0,08	0,60	1,17	0,43	0,019	0,005
61 H 61 V	0,12	0,62	1,24	0,43	0,022	0,006
62 H 62 V	0,12	0,64	1,24	0,44	0,047	0,005
71 H 71 V	0,11	0,63	1,30	0,84	0,010	0,005
72 H 72 V	0,10	0,63	1,29	0,84	0,021	0,005
81 H 81 V	0,12	0,67	1,35	0,89	0,030	0,006
82 H 82 V	0,12	0,64	1,28	0,86	0,046	0,004

2. Rezultati

Pregled natezne površine neprekristaliziranih vroče upognjenih vzorcev (sl. 2) pokaže, da z naraščanjem količine bakra v jeklu postajajo razpoke vse daljše, globlje in bolj odprte.

Bistveno drugačna je natezna površina prekristaliziranih vroče upognjenih vzorcev iz istih jekel (sl. 3). Na prekristaliziranem jeklu se pojavijo podobne razpoke pri približno 0,80 % bakra, kot pri neprekristaliziranem jeklu s približno 5 krat manjšo količino bakra. Vidi se, da prekristalizacija pred ogrevanjem bistveno zmanjša vročo krhkost površine jekla zaradi oligoelementov.

Makrostruktura litih vzorcev pokaže, da so v jeklu s povečano količino bakra avstenitna zrna velika, v jeklu s povečano količino kositra pa precej manjša (sl. 4 do 7). Zaradi prekristalizacije se zmanjšajo avstenitna zrna (sl. 8).

Razpoke, ki nastanejo na natezni strani preizkušancev, so tem globlje, čim daljše so in čim večja so avstenitna zrna. Globina razpok naraste do 4 mm z večanjem količine bakra od 0,15 do 0,85 %, pri vsebnosti kositra 0,011 %. Povečanje globine razpok je minimalno pri nizkem bakru 0,15 % in naraščajoči količini kositra od 0,011 do 0,047 % (sl. 9). Na sliki 10 se vidi, da je s prekristalizacijo doseženo bistveno zmanjšanje globine razpok tudi pri jeklu z 0,85 % bakra in 0,047 % kositra.

Značilna je oblika razpok. Večinoma so zelo pokončne na upognjeno površino in so interkristalne. Dno razpok ni koničasto, temveč je podobno črki U. To pomeni, da ima slabo deformacijsko

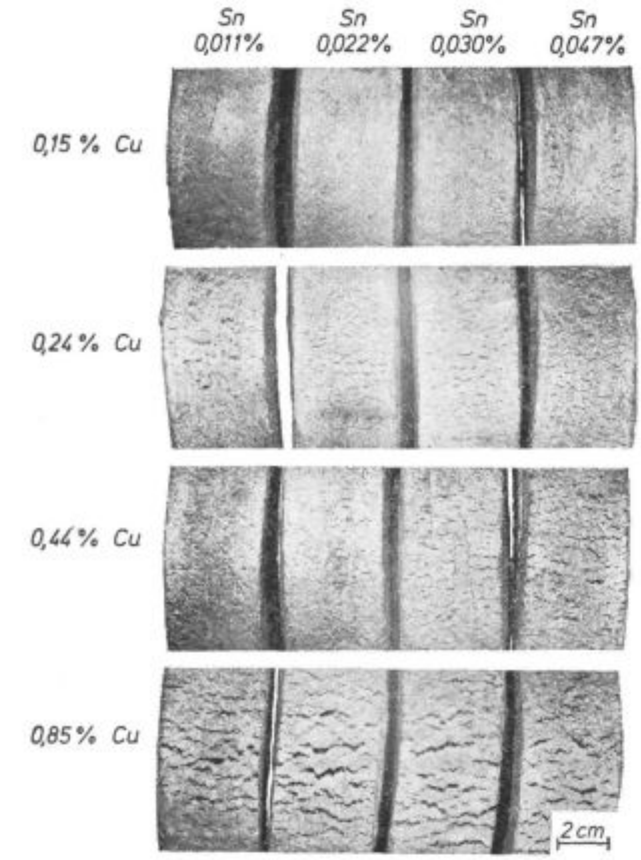
This requirement can be satisfied applying as cast samples for hot bending test. The quantitative evaluation of defects on bent surface helps to obtain the informations necessary to explain the influence of various factors on the hot shortness of ingot surface. For this reason the measurement of the length and counting of the number of craks were performed on the convex side of deformed sample.

1. Steel composition

Basic steel composition was: 0.12 % C, and 1.2 % Mn. This type of steel has been known as highly susceptible to cracking at hot deformation. Copper and tin content of the steel was within 0.15—0.85 % and 0.011—0.050 % range respectively, as can be seen in table 1. The usual contents of tin and copper in this type of steel lie within these ranges. The tests were caried out on as cast samples which were charged to heating furnace either cold i. e. after austenite transformation or hot, i. e. without the transformation.

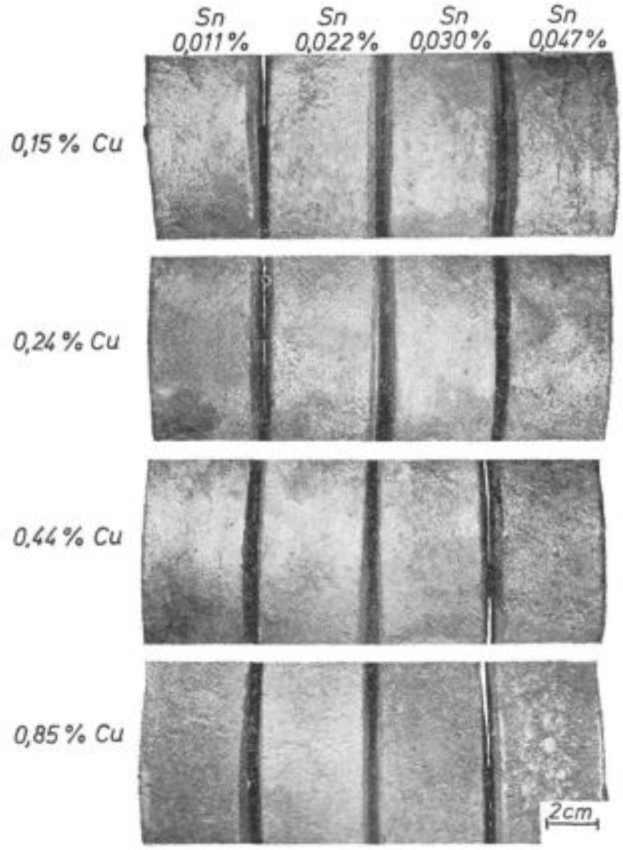
2. Results

Strained surface of the nontransformed hot deformed samples shows (fig. 2) that cracks become longer, deeper and more open with increasing content of copper in steel. The surface of hot deformed samples of the same composition, subjected to the transformation before heating to the deformation temperature, is quite different as can be seen from fig. 3. Surface cracks on the transformed samples with 0.80 % Cu are similar to those in nontransformed samples with approx. five times lower copper content. Hence, the transformation of austenite before heating to the tem-



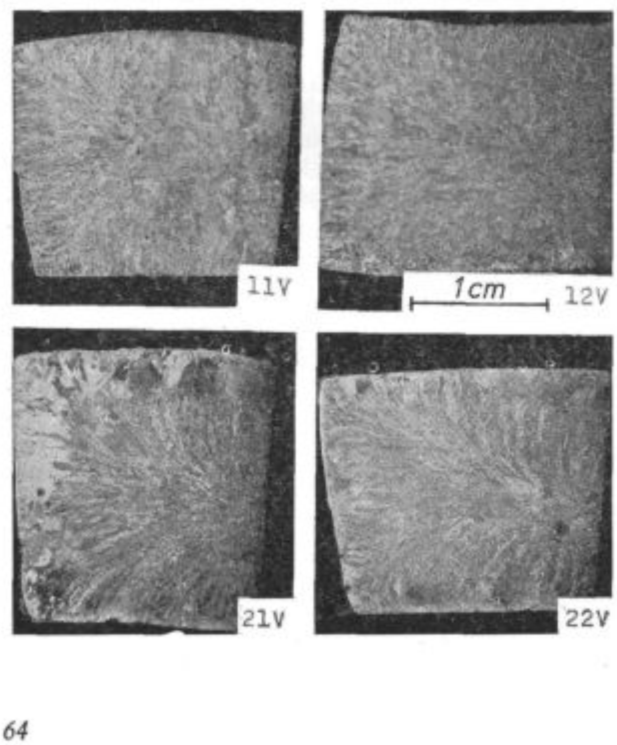
Slika 2
Upognjeni preizkušanci ohlajeni s temperature kristalizacije na temperaturo deformacije.

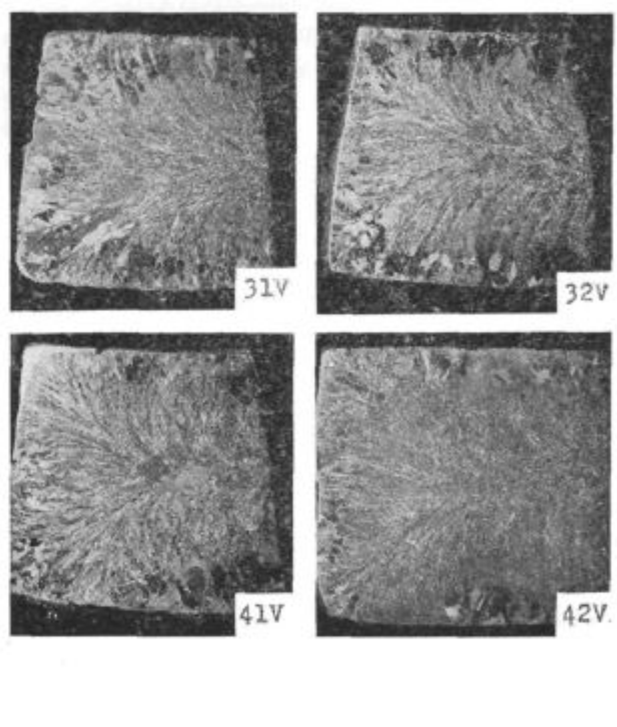
Fig. 2
Samples deformed after cooling from solidification to deformation temperature.

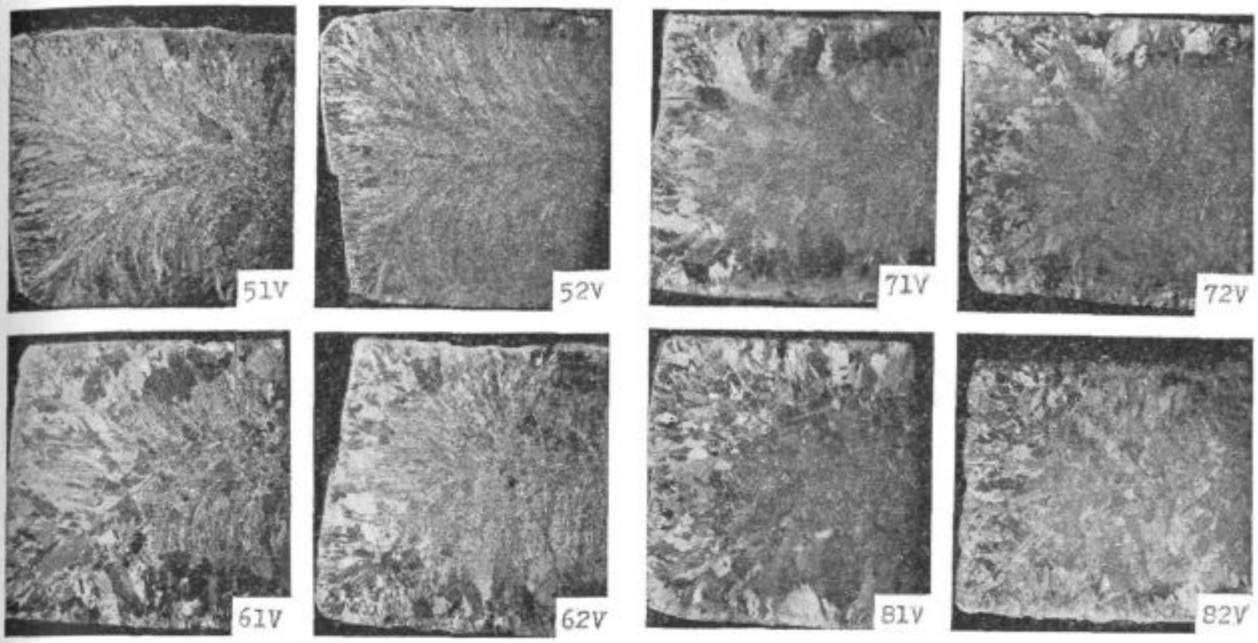


Slika 3
Upognjeni preizkušanci ohlajeni s temperature kristalizacije na sobno temperaturo in ogreti na temperaturo deformacije.

Fig. 3
Samples deformed after cooling from solidification to room temperature and heating to deformation temperature.







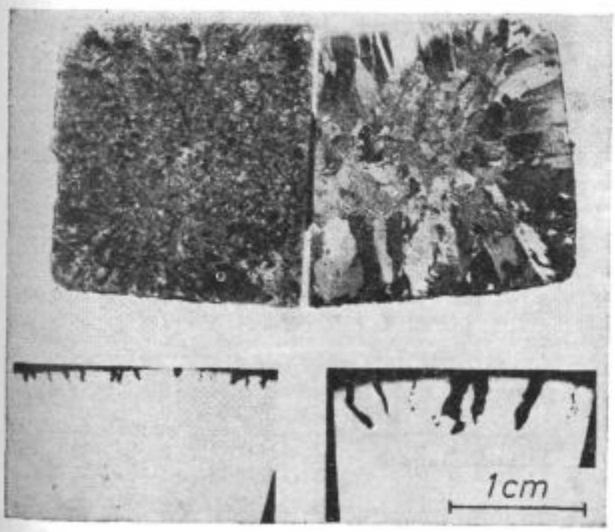
Slike 4 do 7

Makrostruktura prečnega preseka preizkušancev iz različnih jekel, ki so bili ohlajeni s temperature kristalizacije na temperaturo deformacije.

Figs. 4 to 7

Macrostructure of a cross-section of samples of different steels cooled from solidification to deformation temperature.

sposobnost samo meja, ki je oslabljena zaradi penetracije bakra. Brž ko ni več opaziti večje obogatitve, se razpoka ustavi in meja avstenitnega zrna lahko brez škode prenese raztezno deformacijo. Povečanje količine bakra vodi k rahlemu



Slika 8

Makrostruktura preizkušanca, ki je bil ohlajen (desno) in ogret (levo) na temperaturo deformacije. Jeklo z 0,86 % Cu in 0,046 % Sn.

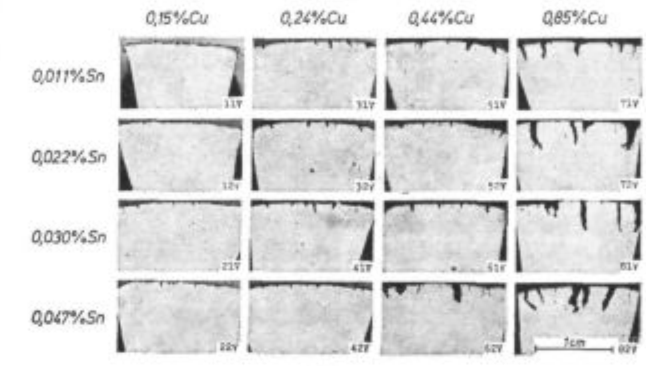
Fig. 8

Macrostructure of samples heated (left) and cooled (right) to deformation temperature showing surface cracks formed by bending. Steel with 0.86 % Cu and 0.046 % Sn.

perature of deformation significantly decreases the hot shortness of steel surface due to residuals.

Macrostructure of as cast samples shows bigger grains of austenite in steel with increased copper content as compared to the steel with increased amount of tin (figs. 4 to 7). Transformation decreases the grain size of austenite (fig. 8).

Surface cracks are the deeper and longer the coarser is the grain of austenite. The depth of cracks amounts to 4 mm when copper content of steel increases from 0.15 % to 0.85 % at 0.011 % Sn. The lowest increase in crack depth is observed at 0.15 % Cu and at increasing tin content from 0.011 to 0.047 % Sn (fig. 9).



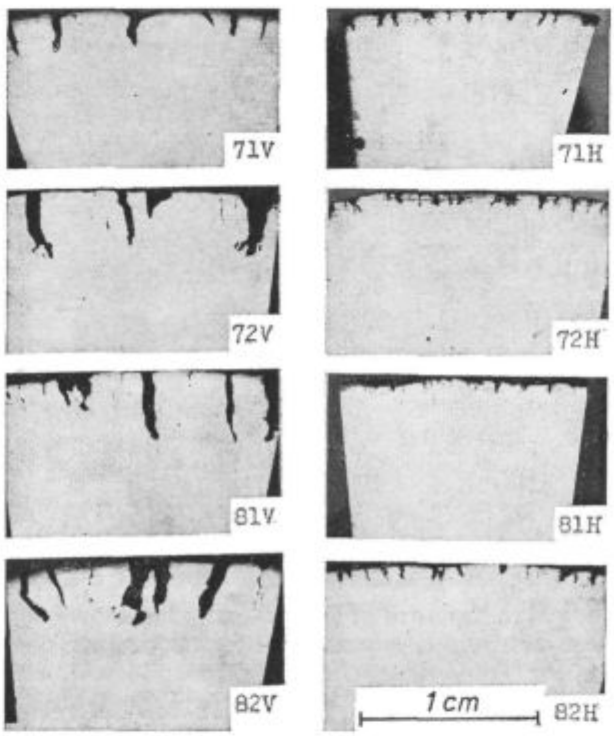
Slika 9

Prečni presek upognjenih preizkušancev, ki so bili ohlajeni na temperaturo deformacije.

Fig. 9

Cross-section of bent as cast samples cooled to deformation temperature.

zmanjšanju gostote razpok (sl. 11), obenem raste dolžina in globina razpok. Tudi povprečna dolžina razpok raste skoraj linearno z naraščanjem količine bakra in kositra. Kaže, da vpliv bakra prevladuje nad vplivom kositra, ki povzroča več razpok, ki so bolj plitve kot pri vzorcih z visokim bakrom (sl. 9).



Slika 10

Globina razpok nastalih pri vročem upogibu na jeklih ohlajenih (levo) in ogretih (desno) na temperaturo upogiba.

Fig. 10

Depth of cracks generated by hot bending in steels cooled (left) and heated (right) to the deformation temperature.

3. Industrijski preizkus

Kljub selektivnosti metode, ki je bila potrjena z razlikami v deformabilnosti jekel z različnim dodatkom bakra in kositra, je mogoče trditi, da je metoda uspešna šele, ko laboratorijske rezultate potrdi tudi industrijski preizkus.

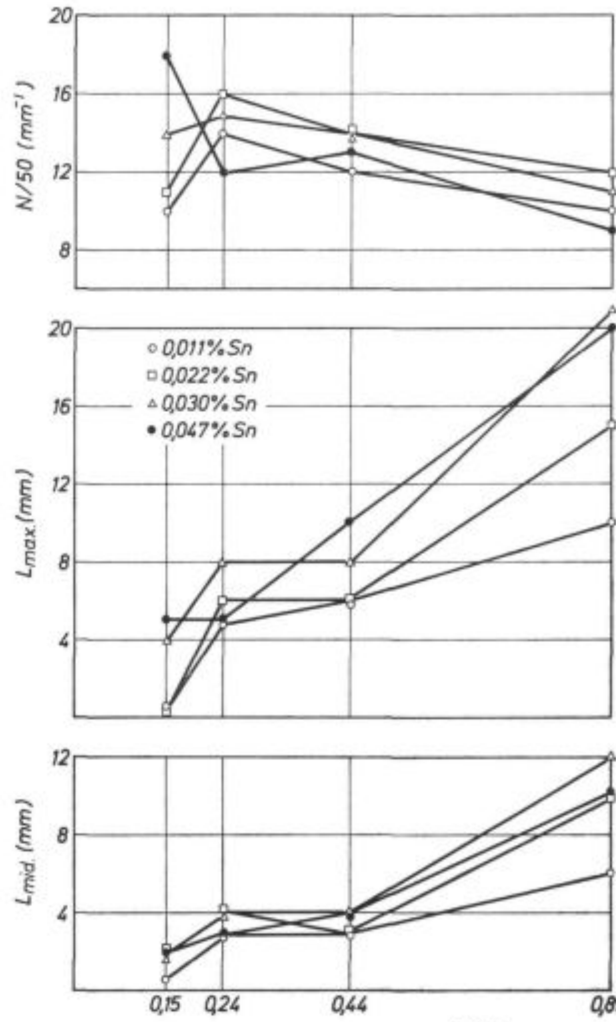
V 8-tonski obločni peči smo izdelali enako jeklo z 0,89 % bakra in 0,032 % kositra in vlili dva 4-tonska ingota. Enega smo po vlivanju, pred zalaganjem na ogrevanje, ohladili do temne površine in s tem dosegli prekristalizacijo, drugega smo vročega takoj po stripanju dali v peč na ogrevanje za valjanje. Nato smo oba bloka izvaljali enako. Prekristaliziran blok je dal slabe z bistveno boljšo kvaliteto površine (sl. 12, 13).

Rezultati industrijskega preizkusa potrjujejo reprezentativnost preizkusa vročega upogibanja,

It is clear from fig. 10 that the transformation significantly decreases the depth of cracks even in the samples containing 0.85 % Cu and 0.047 % Sn.

The shape of cracks is very characteristic. In a majority of cases the cracks are approx. perpendicular to the surface strained at bending. The bottom of cracks is U-shaped and shows that only boundaries weakened by penetration of copper and tin display poor workability. Crack propagation stops at the depth where the grain boundary is not enriched anymore in copper, unmodified grain boundaries of austenite sustain tensile deformation without cracking.

An increase in the content of copper in steel results in a slight decrease in the number of surface cracks per unit area (fig. 11), however the length and the depth of cracks increase. The ave-



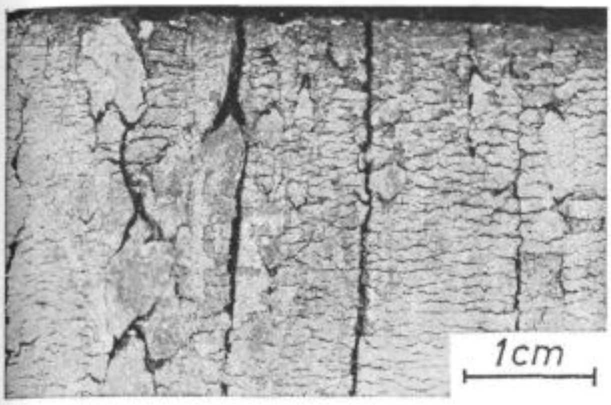
Slika 11

Vpliv naraščanja količine bakra in kositra na število (N), max. dolžino (L_{max}) in povprečno dolžino (L_{mid}) razpok na površini jekla.

Fig. 11

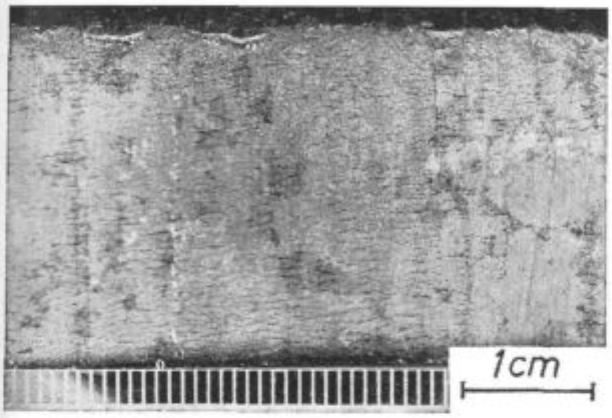
Influence of copper and tin on the number (N), the max. length (L_{max}) and the midle length (L_{mid}) of cracks on steel surface.

ki je pokazal, da je z ohlajanjem vzorcev po vlivanju mogoče zmanjšati pokljivost površine jekla z lito strukturo in z 0,85 % bakra.



Slika 12
Površina vroče založenega industrijskega ingota po valjanju v gredico 135 × 135 mm.

Fig. 12
Surface of hot soaked industrial ingot after rolling to 135 × 135 mm billets.



Slika 13
Površina hladno založenega industrijskega ingota po valjanju v gredico 135 × 135 mm.

Fig. 13
Surface of cold soaked industrial ingot after rolling to 135 × 135 mm billet.

D. SKLEPI

Preizkus vročega upogibanja je bil uspešno uporabljen za ugotavljanje pokljivosti jekla zaradi selektivne oksidacije. Ocenitev števila in dolžine razpok na površini, deformirani z natezno deformacijo, je omogočila opredelitev vpliva bakra in kositra na pokljivost jekla.

rage length of cracks increases almost proportionally to the increasing amount of copper and tin. It seems that the influence of copper is more harmful than that of tin. This element causes a higher number of cracks of lower depth as compared to that observed in samples with a high copper content (fig. 9).

3. *Industrial test*

The selectivity of the metod was confirmed by determination of the individual influence of copper and tin on the hot shortness of steel. It can not be, however, considered as successful unless a good agreement between laboratory results and results of industrial test is found. Therefore, an industrial test was carried out on two 4 ton ingots of a steel containing 0.89 % Cu and 0.032 % Sn, made in a 8 tons electric arc furnace. One ingot was cooled after stripping to »black surface« temperature to obtain the transformation whereas the other was charged to heating furnace immediatly after stripping. Both ingots were heated to the same temperature and rolled in the same way. A much better quality of slab surface was obtained from the ingot which endured transformation before heating (fig. 12) as compared to the other ingot (fig. 13). Consequently, the industrial test confirmed the validity of the hot bending test which showed that the hot shortness was decreased when 0.85 % Cu steel with as cast structure was submitted to the transformation of austenite before heating to deformation temperature.

D. CONCLUSIONS

The hot bending test was successfully applied for the estimation of the hot shortness of steel caused by selective oxidation. The assessment of the number and the length of surface cracks on strained surface of deformed samples made it possible to determine the influence of the content of copper and tin on the hot shortness of steel. The use of as cast samples made it possible to connect the results of the bending test to the behaviour of blocks at industrial rolling.

Coarser grains and a lower number of deeper and longer cracks are observed in steel with increased copper content. At higher content of tin a lower grain size and a higher number of shorter cracks of lower depth are found.

The cooling of as cast steel below the transformation temperature before heating to the rolling temperature made it possible to attain a considerable improvement of hot workability. Cold soaked steel with 0.85 % Cu displayed a similar hot workability as hot soaked steel with approximately 0.15 % Cu.

Uporaba litih preizkušancev je omogočila povezavo med rezultati, dobljenimi pri vročem upogibu, s ponašanjem blokov pri industrijskem valjanju.

V jeklih z mnogo bakra so kristalna zrna večja, razpoke manj pogoste, dolge in globoke. Če v jeklu prevladuje vpliv kositra, so zrna manjša, razpoke krajše, bolj številne in manj globoke. S prekristalizacijo litega jekla pred ogrevanjem za vroče valjanje je mogoče pomembno zmanjšati pokljivost.

S prekristalizacijo jekla z 0,85 % bakra je mogoče doseči enako vročo krhkost pri vročem upogibu in pri valjanju blokov, kot pri neprekristaliziranem jeklu s približno 0,15 % bakra.

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