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THE ANALYSIS OF DEFECTS ON CONTINUOUS CAST BILLETS

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First the article presents the system of sampling and methods of correction of defects on continuous cast billets and rolled steel concrete bars. Although the chemical composition of these billets (with increased contents of manganese and oxygen) is adequate to the standard chemical composition (DIN 488 - BSt 500S) there are gas blow holes and cracks as well as central and peripheral segregation. The point is in unsatisfactory deoxidation of hot cracks which develop during solidification. A prove that the hot cracks are decarbonisation in cracks are inclusions of Si, MnS, Fe, S, respectively an increased content of accompanying elements. The hardness value indicates that the rolling process develops regularly, i.e. in the area of recrystallization of metal.

Key words: *continuous cast billets, analysis of defects, macro and microscopic investigations*

Analiza grešaka na kontinuirano lijevanim gredicama. U članku je prvo dat sustav uzimanja uzoraka i metode ispitivanja grešaka na kontinuirano lijevanim gredicama i valjanim čeličnim šipkama za beton. Mada ukupni sastav ovih gredica (uz povećani sadržaj mangana i kisika) odgovara normiranom kemijskom sastavu (DIN 488 - BSt 500S), nazočni su plinski mjehuri i pukotine, kao i centralne i periferne segregacije. U pitanju je neodgovarajuća dezoksidacija, vruće pukotine koje nastaju tijekom skrućivanja. Dokaz da su vruće pukotine je odugljeničenje u pukotinama. Uključci su Si, MnS, Fe, S, odnosno povećani sadržaj oligoelemenata. Vrijednosti tvrdoće ukazuju da se proces valjanja odvija pravilno, tj. u području rekristalizacije metala.

Ključne riječi: *kontinuirano lijevane gredice, analiza grešaka, makro i mikroskopska istraživanja*

INTRODUCTION

Thanks to its excellent properties the steel production is in continuous progress: in 2000 - 885,7 Mt, 2002 - 945,1 Mt, and in 2004 - 1054 Mt. [1, 2].

From the produced amount of steel 80 % is processed through plastic working (forging, pressing, extrusion, rolling and bending), however mostly by rolling [3].

In developed countries over 70 % are flat sections, up to 8 % are pipes, and simple and complex sections are up to 20 %. Regarding the needs in construction engineering the use of steel concrete bars also increases and amounts up to 6 % of the total amount of rolled products (rolled wires participate up to 10 % and the rest concerns other sections).

The processes of production, casting, heating and processing are accompanied by significant imperfections which have an adverse influence on the quality of charge. Insisting on the quality is of great importance for the production. If neglected, it reflects on increased amount of material consumption, increased cost, decreased production and delay of delivery time.

All defects can be separated into three main groups [4]:
- melting and casting defects,
- charge heating up defects,
- deformation working defects.

Formation of defects was systematically monitored in Croatia, within Željezara Sisak and Institute for Metallurgy Sisak, and a number of books, articles and defects atlases were published [4 - 13].

It is understandable that the world pays especially great attention to this problem area. Professional literature in the world abounds with various presentations, books, atlases, articles, and symposium reports. Here are mentioned some works dealing with the same subject matter as this article [14 - 24].

Several kinds of steel bars are produced in Željezara Split [25]. Some defects have been noticed in the production course of continuous-cast billets 125 × l25 mm and

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rolled products. The cause and characteristics of the formation of defects have to be determined.

The aim of this work is to carry out the analysis of defects appearing on continuously cast billets 125 × 125 mm and in the course of rolling concrete steel bars through some rolling passes in Željezara Split d.o.o.

EXPERIMENTAL PART

Specimens and methods of investigation

The formation of gas blow holes in continuously-cast billets is a frequent phenomenon. Therefore, for the investigation of causes of these defects two specimens of 125 × 125 billets from various melts are used: nr. 1 and nr. 2. From the billet nr. 1 a specimen was taken during the rolling on fully continuous rolling mill - size Ø 40 mm (with visible cracks) - nr. 3.

Several methods were applied at investigation process:

a) determination of melt basic chemical composition - investigation was performed with radiation spectrometer of ARL company,
b) determination of gas amounts in steel (N_2, O_2) by classical chemical analysis with LECO analysis device,
c) determining of the structure and composition of enclosures:
   - macro structure by digital photo apparatus and microscope Leika WILD M 3Z,
   - determining of the segregation in steel by the method of sulphur print,
   - microscopic investigation:
     - with optic microscope Olimpus VANOX-l,
     - with electronic microscope JBM-35CF,
     - by the method of wave dispersion analysis of *x*-rays (EDX),
d) hardness measuring:
   - hardness according to the hardness measuring device HPO 3000 Brinell,
   - hardness according to the hardness measuring device MIKRODUR II-V Vickers.

Results and Discussion

Determination of melt chemical composition and steel gases

The chemical composition of investigated metal melt (specimen) is presented in the Table 1., and in Table 2. a standard chemical composition according to DIN 488-BSt 500S.

By comparing chemical composition in Table 1. and 2., it can be seen that investigated melt, with a little increased contents of Mn and O has an adequate chemical composition as per standard. (The presence of oxygen is explained by missing deoxidation, and the presence of nitrogen is the result of melt blowing through by oxygen at steel fabrication).

Table 1. **Chemical composition of investigated melt / %**
Tablica 1. **Kemijski sastav ispitivane taline / %**

C	Mn	Si	P	S	Al
0,164	0,673	0,179	0,026	0,036	0,003
Cu	Ni	Cr	As	Ti	V
0,321	0,098	0,103	0,019	0,001	0,001
Nb	Mo	B	Zr	O_2	N_2
0,020	0,015	0,0002	0,001	0,0068	0,0112

Table 2. **Standard chemical composition / % - DIN 488-BSt 500S**
Tablica 2. **Normirani kemijski sastav / % - DIN 488-BSt 500S**

C	Mn	Si	P	S	Al
0,14-0,22	0,50-0,60	0,15-0,35	0,05 max	0,05 max	0,006 max
Cu	Ni	Cr	Sn	N_2	
0,40 max	0,30 max	0,30 max	0,05 max	0,012 max	

Defining structure and composition of inclusions

Macro investigating

By macroscopic investigating it was defined that gas holes-bubbles in specimen 1. are very pronounced, 2 cm, under the crust. Figure: 1.a, 1.b, 1.c.

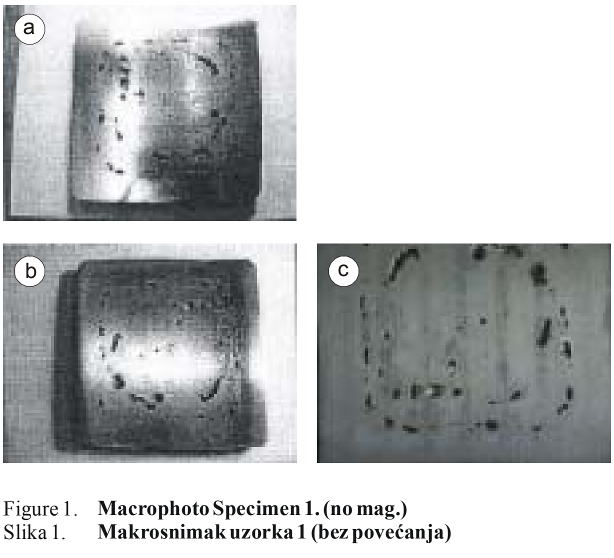

Figure 1. **Macrophoto Specimen 1. (no mag.)**
Slika 1. **Makrosnimak uzorka 1 (bez povećanja)**

In Specimen 2. the bubbles are very near the billet surface, at a distance of 3 mm, (Figure 2.a). In some places the bubbles are in touch with the surface or appear on it, Figure 2.b, 2.c. There are also cracks as well as enclosures.

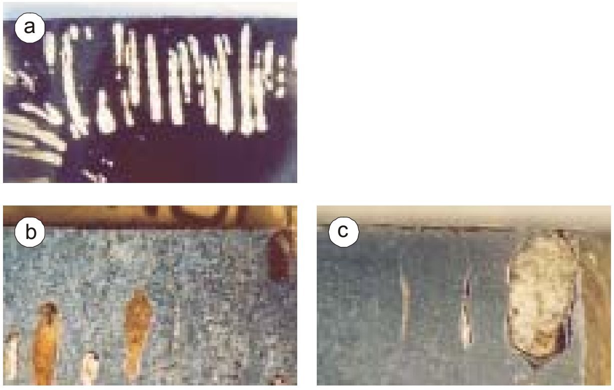

Figure 2. **Macrophoto - Specimen 2.a mag. 2,5×, 2.b mag. 8×, 2.c mag. 20×**
Slika 2. **Makrosnimak uzorka 2.a povećanje 2,5×, 2.b povećanje 8×, 2.c povećanje 20×**

By macroscopic inspection of Specimen 3., some scabs (crust) were detected on the side of the specimen, and on the surface some surface cracks were noticed, which can be seen in the Figure 3.a, 3.b, 3.c. Segregation attendance was defined by Baumann method, Specimen 1. and 3.

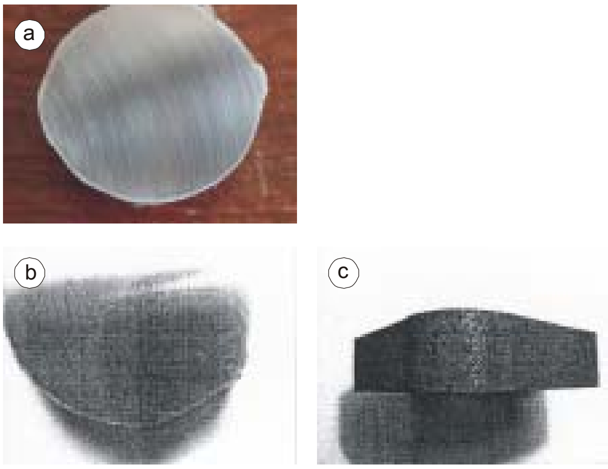

Figure 3. **Macro photo (no mag.)**
Slika 3. **Makrosnimak uzorka 3 (bez povećanja)**

On the Specimen 1. a uniform disposition of sulfur is noticeable with a pronounced central segregation and less pronounced peripheral segregation - Figure 4. (also the inclusions).

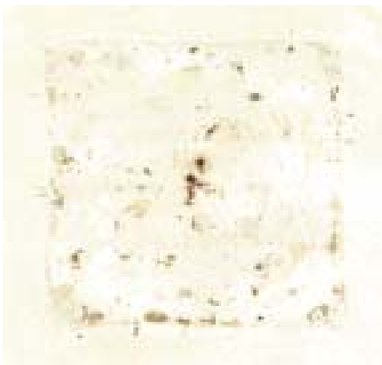

Figure 4. **Baumann's print of Specimen 1.**
Slika 4. **Baumanov otisak uzorka 1**

On the Specimen 3. heterogeneous segregation is more pronounced on single places, which is shown in the Figure 5. (inclusions as well).

These segregations are also proved for the Specimen nr. 2., so no figure is presented.

Figure 5. **Baumsnn's print of Specimen 3.**
Slika 5. **Baumanov otisak uzorka 3**

Microscopic investigation

It has already been mentioned that same cracks and inclusions were detected in the Specimens nr. 2. and nr. 3. and in connection with it microscope investigations were performed.

a) Speciment nr. 2.

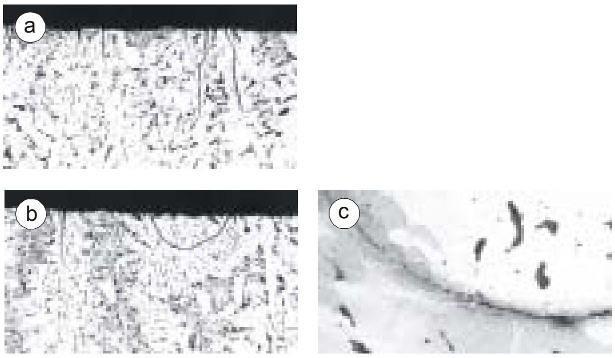

Figure 6. **Microstructure of various cracks: 6.a mag. 50×, 6.b mag. 50×, 6.c mag. 500×**
Slika 6. **Mikrostruktura raznih pukotina: 6.a povećanje 50×, 6.b povećanje 50×, 6.c povećanje 500×**

The microscopic investigation of Specimen nr. 2. give the Figure 6. - various cracks. The cracks are fulfilled with oxides, and around them are dotted dispersed oxides Figure 6.c. Figure 7.a and 7.b presents connection of blow holes with the billet surface.

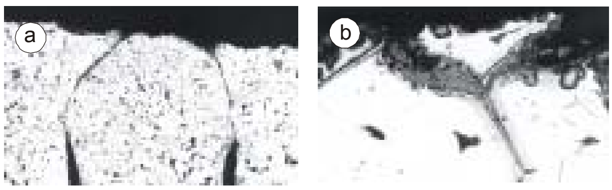

Figure 7. **Micro photo of connection crack-blow hole-billet surface 7.a mag. 50×, 7.b mag. 500×**
Slika 7. **Mikrosnimak spoja pukotina - mjehur - površina gredice: 7.a povećanje 50×, 7.b povećanje 500×**

Surface microstructure is ferritic-pearlitic one, however considerably heterogeneous. The areas of polyhedron grains can be noticed with acircular morphology which indicates to irregular cooling. The presence of a great number of blows indicates to the deficiency of steel deoxidation and quick crust formation at solidification. The blows being near the surface there is a possibility for them to be welded in the course of rolling. The problem are the blows appearing on the surface because during the heating up in continuous type furnace (previous to rolling) they can be oxidized and subsequently lead to surface defects. In the cracks on the billet surface (Figure 7.b) and in same places deeper (Figure 6.c) dark particles appeared in oxide groups.

In these particles-inclusions the presence of Cu and Sn was defined which can be seen in the Figure 8.

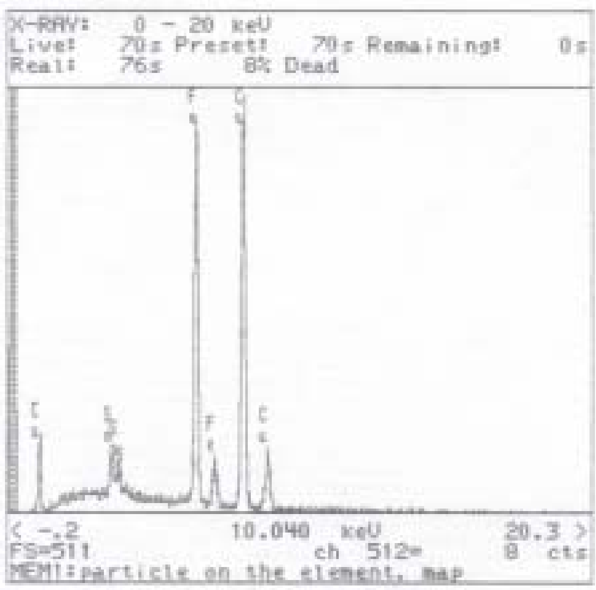

Figure 8. **The analysis of inclusions by method EDX**
Slika 8. **Analiza uključaka EDX-metodom**

It means that a diffusion occurred and an increase of the contents of accompanying elements (oligoelements), towards the surface and on the surface.

b) Speciment nr. 3.

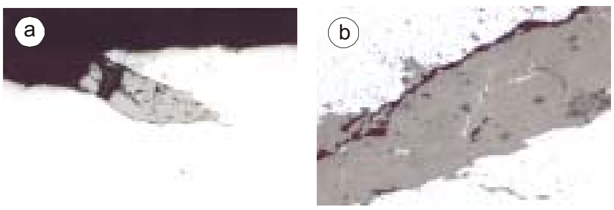

Figure 9. **Microscope picture of a small crack (without the etching): 9.a magnified 50×, 9.b magnified 500×**
Slika 9. **Mikroskopska snimka male pukotine (bez nagrizanja): 9.a povećanje 50×, 9.b povećanje 500×**

On this specimen are visible some big and some small cracks as well as some inclusions - Figure 9.a, 9.b.

The analysis of this crack is made also by specimen etching - Figure 10.a and 10.b. In the Figure 10.a the surrounding area of the crack is presented, 10.b the phenomenon of decarbonisation is noticed. In the Figure 10.b a detail of the crack is presented. There is a great number of inclusions around the defect.

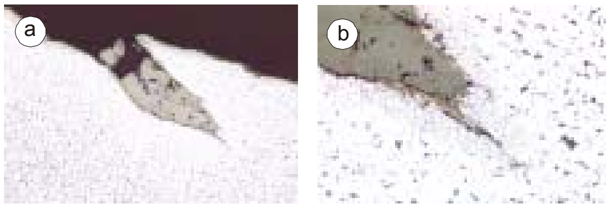

Figure 10. **Microscope picture of the surrounding area of the crack: 10.a magnified 50×, 10.b magnified 200×**
Slika 10. **Mikroskopska snimka okoline pukotine: 10.a povećanje 50×, 10.b povećanje 200×**

Upon a microscope inspection of a small crack some more detailed inspections for large cracks are performed - Figures 11., 12.

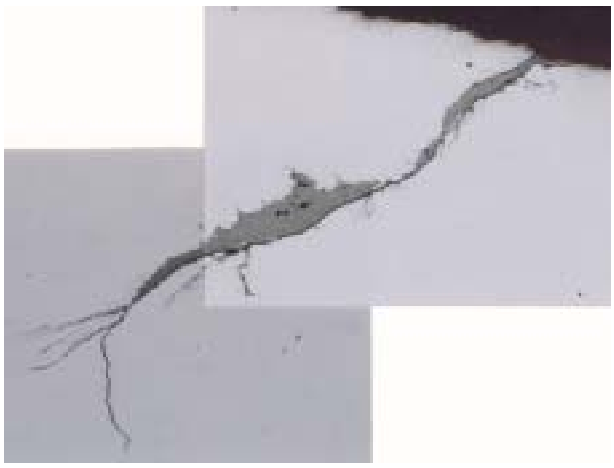

Figure 11. **Microscope photo of a great crack: magnified 50×**
Slika 11. **Mikroskopska snimka velike pukotine: povećanje 50×**

In the Figure 11. a great crack is shown. Some inclusions and decarbonisation effects can be noticed, and on the very end of the crack there starts its branching.

The Figure 12.a presents a detail of the beginning of a great crack. In the Figure 12.b a detail at the end of the crack is presented. It is noticeable that in the crack is a great number of inclusions whose origin and composition will be defined by an additional analysis . The Figure 12.c presents the structure of metals. In the picture a ferrite-pearlitic structure can be seen, lamellas are very near which indicates to the fact that the cooling process was fast enough.

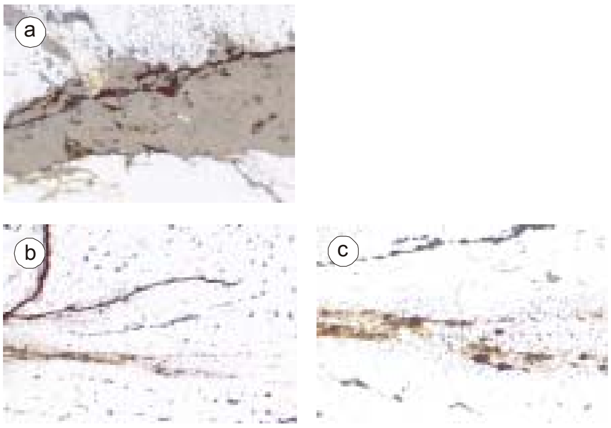

Figure 12. **A microscope photo of a great crack: 12.a mag. 500×, 12.b mag. 200×, 12.c mag. 500×**
Slika 12. **Mikroskopska snimka velike pukotine: 12.a povećanje 500×, 12.b povećanje 200×, 12.c povećanje 500×**

In order to define the kinds of inclusions and behavior of materials a macro- fracture was performed on the place were the crack (the crack was opened) - Figure 13.

Figure 13. **Presentation of an opened crack: mag. 12×**
Slika 13. **Prikaz rastvorene pukotine: povećanje 12×**

From the Figure 13. it can be seen that the inclusions are in the dark part of the specimen. However, in the other part of the specimen the fracture is transcrystalline, i.e. through the whole grains. It means, behind the crack the fracture is tough.

Based on this investigations it can be concluded that the cracks appeared in the process of casting , i.e. solidification of continuous cast billets in order to accelerate the cooling process, which is indicated by a close relationship of ferrite-pearlitic lamellas. The inclusions of unknown composition being proved on this specimen an additional analysis was carried out with a scanning microscope, Figure 14. and 15. (The microstructure is closely tied by lamellas and even more circular bainite appears).

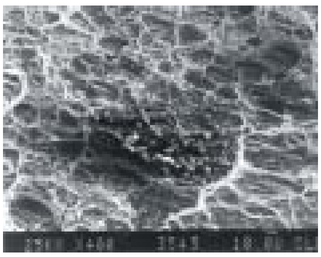

Figure 14. **A microscope photo under the fracture**
Slika 14. **Mikroskopska snimka ispod pukotine**

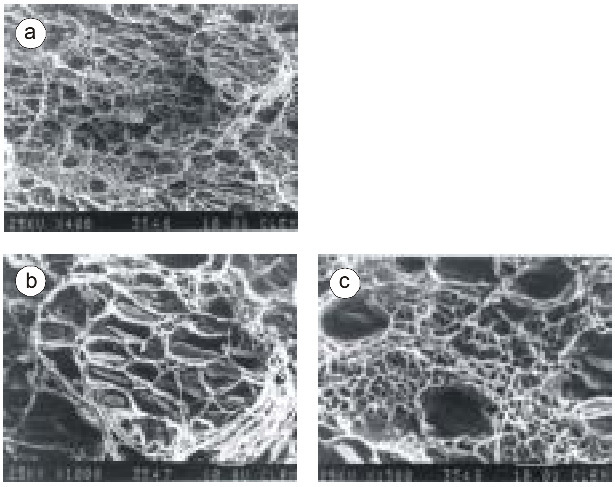

Figure 15. **Microscope photo of big and small inclusions**
Slika 15. **Mikroskopska snimka velikih i malih uključaka**

The Figure 14. is shot under the fracture. Small holes (inclusions) in the specimen are clearly visible. The inclusions have different size and their appearance is shown in the Figure 15. Microstructure consists of closely connected lamellas, and even more there develops circular bainite.

In order to define the composition of inclusions, an additional EDX analysis, and obtained results are shown on the Figure 16.

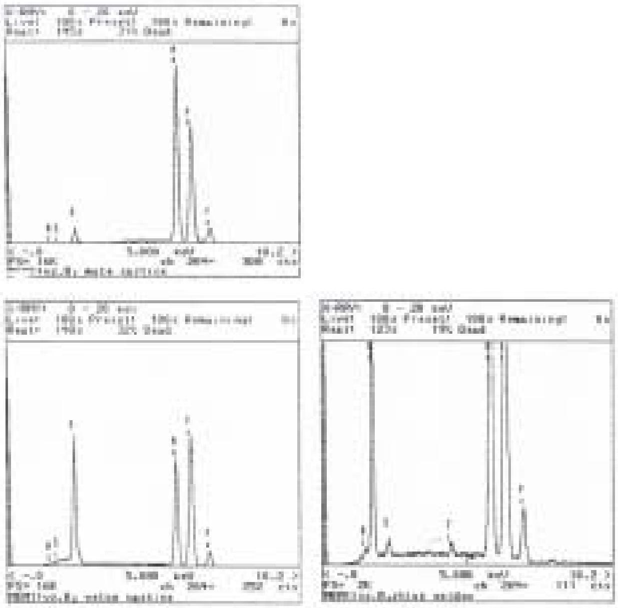

Figure 16. **Analysis of inclusions by EDX-method**
Slika 16. **Analiza uključaka EDX-metodom**

On the basis of this analysis it follows that available inclusion Mn, Fe, S, Si, Al, and MnS with the presence of oxides and accompanying elements, which is affirmed also on the Specimen nr. 2.

Hardness testing

As for defining possible changes (solidification during plastic deformation - concrete steel bars rolling) hardness testing was carried out on the Specimens nr. 1. and nr. 3. - according to the lay-out, Figure 17. (with the values).

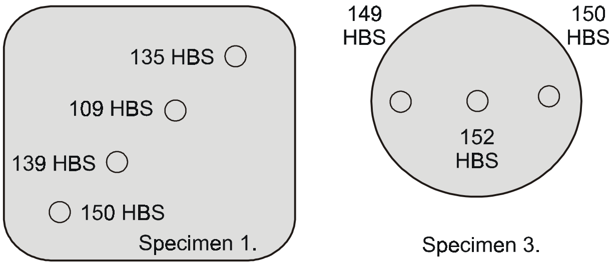

Figure 17. **Lay-out of the place where the hardness is measured with the values**
Slika 17. **Skica mjesta gdje je izmjerena tvrdoća sa vrijednostima**

The Specimen no 1. has a deviation during a measuring because of specimen defect (near of gas bubble). Taking into account the value of the hardness a small increase is observed depending on rolling passes. Earlier it was pointed out that on the specimen nr. 3. on the place where was a crack a macro fracture was performed (the fracture is open). As for the completeness of testing the hardness was defined on the places of fracture (beside the crack by Vickers method (micro-hardness 7 N), see Figure 13. The hardness 151 - 167 HV7.

As the hardness according to Brinell and Vickers are equalized to the value 300, it means that on the place of fracture the hardness was 151 - 167 HBS. These values are within dimensional tolerance.

Based on the results of hardness measuring it can be concluded that during the rolling process there is no material hardening.

CONCLUSION

On the basis of personnel investigating of continuous cast billets 125 × 125 mm and during the processing of rolling in Željezara Split following conclusions can be made:

1. Depending on fabrication technology and steel processing by deformation specific defects develop in some stages of production. The arise of defects should be monitored, their reason defined in order to decrease their frequency. This should be done also because the defects take along to increase of material consumption, increase of prime cost, decrease of production, lost of the market etc.
2. A systematic monitoring, analyzing, defining the causes of defects on steel inputs and rolled products has been particularly implemented in Željezara Sisak, Institute of metallurgy as well as in the world. There is a great number of published studies, articles, reports, and atlases. They all present a good basis for a future production and working of steel with a clear intention of preventing the appearance of defects.
3. By investigating chemical composition of continuous cast billets (Specimen 1.) from Željezara Split it was found out that with a little increased content of manganese and oxygen this composition equals to the nominal chemical composition (DIN 488-BSt 500S). The presence of nitrogen is explained by blowing-through the melt at the manufacturing with nitrogen.
4. An increased content of oxygen in continuous cast billets and formatting of blow holes (Specimen 1. and specimen 2.) arranged under the surface (but also along the cross section) is explained by incompletely conducted deoxidation. The reaction of boiling out at solidification process is continued, the fabricated gas stays imprisoned in steel and forms blow holes. As on the investigated semi-products (Specimen 3.) in the course of concrete bars rolling the blow holes were not detected, or they were decreased very much, it suggests that at rolling process and same larger reduction the holes are welded. Aside from that attention should be paid to deoxidation of molten metal s prior to the process of casting. There should be also a normal process of cooling because at a fast solidification the gas does not succeed to leave the molten metal.
5. Although the content of sulfur was in allowed values it was noticed that it was unequally arranged with a pronounced central and less pronounced peripheral segregation. It tells us that at the molten metal parameters should be ladle-controlled in order to ensure more equal sulfur arrangement, i.e. a better micro purity of steel.
6. There appear twisting cracks, wide-spread, fulfilled with inclusions and segregations and with decarburized surface. It means, the point are hot cracks that form at casting i.e. solidification. Although it is considered that the cracks form also at too high casting speed or temperature, in our case it is a failure at cooling process that caused development of stresses and surface contraction. The proof that the cracks are hot are decarburized surfaces alongside cracks (but also in the depth of the cracks). It developed in the course of billets heating up before plastic deformation. Too fast cooling may also be the reason of fast crust solidification and gas capturing in the steel. The microstructure, that should be ferritic-pearlitic structure, conceals it with a normal arrangement of lamellas. The real structure is with closely connected lamellas, even more there appears circular bainite, that is not expected at normal cooling condi-

tions and this chemical composition. However, this should be checked because such a structure can develop at irregular process of rolling as well, which means also irregular cooling.

7. In all specimens and melts are found inclusions of different structure and shape. So, there are Si and Mn phases in elemental state, which indicates to insufficient state of solution at steel fabricating. Particularly inclusions of MnS, Fe, S, oxides (a bit of titanium) as well as accompanying elements. Development of gas blow holes, hot cracks but also of a number of inclusions requires a more attention and responsibility at manufacturing steel melts. All the found and analyzed defects originate from melt fabricating, i.e. they are of steel-like origin.
8. Based on the values and change of bar hardness at the rolling process it can be noticed that there comes to no solidification. It proves that the rolling process develops regularly, i.e. in the area of metal recrystallization.

On the basis of these conclusions we meet with same guide lines and recommendations for further work in Željezara Split:

- to optimize and strictly control the parameters of steel production in electric furnace, particularly crucible furnace at continuous casting.

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