International Journal of Research Studies in Science, Engineering and Technology
Volume 6, Issue 7, 2019, PP 15-21
ISSN : 2349-476X

The Control of Pinhole and Crack Defect on the Surface of Cold Heading Steel Billet

Wei Zhang[1,2], Liqiang Zhang[2*], Ali Naqash[2*], Aonan Zhao[2], Chaojie Zhang[2]

[1]Jiangyin China Resources Steelmaking limited company, Jiangyin, 214404,China
[2]School of Metallurgical Engineering, Anhui University of Technology, Ma'anshan, 243002,China

***Correspondence Author:** Liqiang Zhang, Ali Naqash, School of Metallurgical Engineering, Anhui University of Technology, Ma'anshan, 243002, China. Email: zhangsir508@13.com, naqash.sanaullah322@gmail.com*

ABSTRACT

In this paper, the experiments were carried out on the cold heading steel containing boron 10B21 which have several cracking phenomena in its production process. Through macroscopic analysis, microstructure analysis, scanning electron microscope, energy spectrum analysis and other experiments, it was found that the pinholes and crack defects on the surface of billet are due to N and O contents, electromagnetic stirring, protective slag and temperature etc. The optimization process was proposed to reduce pinholes and crack defects. Through the optimization process, the defects such as pinhole and surface crack of casting billet were effectively solved. Finally, the wire rod was uniformly organized with the grain size above the 8 grades, and the qualified rate of the rod forging was 100%.

Keywords: *Cold heading steel; Billet; Pinhole; Cracks, Mould slag*

INTRODUCTION

Boron-containing 10B21cold heading steel is suitable for the manufacturing of fasteners of grade 8.8 and above. The 10B21 wire rod is pickled and phosphatized and drawn into cold heading steel wire. The cold heading steel wire is shaped into fasteners such as screws and bolts. During the processing, the material has a high deformation rate, a large degree of deformation and unevenness, so the wire is required to have good cold deformation capacity [1-3].In the continuous casting process of cold heading steel materials, surface defects such as pinholes, angles and transverse cracks occur easily, which further lead to cracking of cold heading steel in the subsequent processing. Therefore, the production of billets without surface defects is a necessary condition for high-quality cold heading steel [4-8]. The processing technology of 10B21 cold heading steel produced by a domestic factory consists of: blast furnace molten iron → desulfurization treatment → converter smelting → argon blowing →LF furnace treatment → continuous casting → billet inspection → casting billet delivery → billet acceptance → billet heating → rolling → controlled cooling → collecting rolls → bundling → packaging [9-10].

In this paper, the pinholes and crack defects of continuous casting billets in a factory were analyzed. The factors affecting and reasons for such defects were explored, and the optimization plans were proposed to reduce these defects and improve the quality of casting billets.

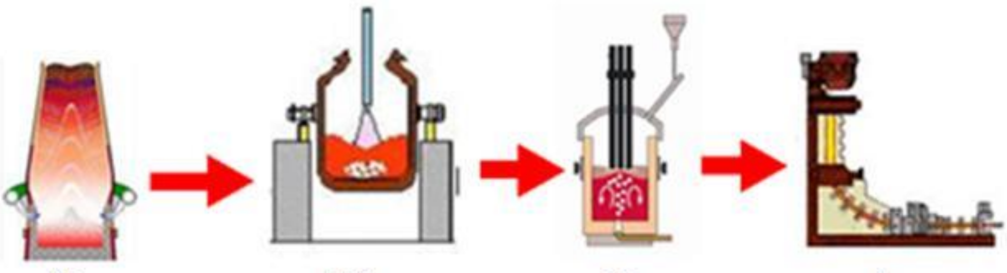

Figure1. *The production process of boron 10B21 cold heading steel*

EXPERIMENTAL

The boron 10B21 industrial production line of cold heading steel as the research platform is used in this paper. The production process of this production line contains 120t oxygen top-blown converter, Ladle furnace (LF), and billet continuous casting. The process flow chart is shown in **Fig. 1.**The control target of W[C] and W[P] at converter blowing endpoint was 0.12-0.16% and 0-0.015% respectively. The tapping temperature was 1610-1645 °C. In the tapping process, lime and fluorite were added to the slag and aluminum was deoxidized, and the tapping process was followed by secondary slag. The LF white slag was desulfurized, and the calcium lime was fed to the inclusions for denaturing treatment. After weak agitation, it was sent for the continuous casting process, and the on-site billet samples were detected and analyzed.

RESULTS AND DISCUSSION

Analysis of Pinhole Defects in Continuous Casting Billet

The results of tundish and mould samples showed that the oxygen and nitrogen contents of molten steel were higher than that of the blast furnace, and the probability of pinholes appearing in the continuous casting billet was larger.

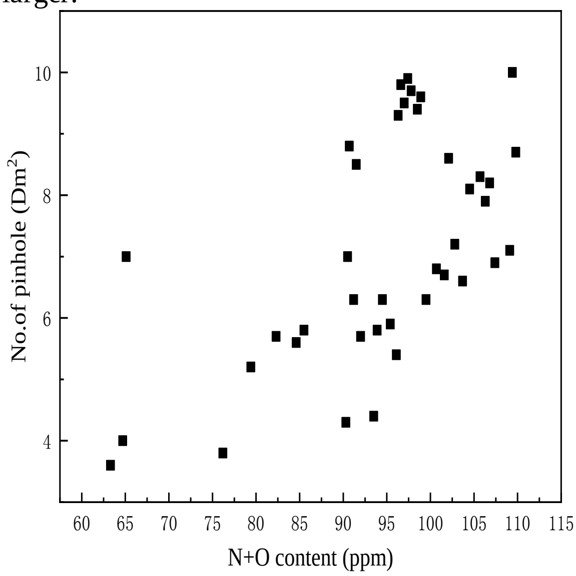

Figure2. *Relationship between gas contents and pinhole density.*

Effect of Oxygen and Nitrogen Contents on the Pinholes of Continuous Casting Billet

It was found that when the contents of oxygen and nitrogen in the molten steel were less than or equal to 30 ppm and 80 ppm respectively, the pinhole of the continuous casting billet will be reduced to a great extent. The defects in continuous casting billets corresponding to oxygen and nitrogen contents were compared in the production process of cold heading steel10B21, as shown in **Fig. 2**.When the sum of oxygen and nitrogen contents was less than 80 ppm, the pinholes of continuous casting billets were less likely to appear.

Effect of Electromagnetic Stirring on Pinholes in Continuous Casting Billets

There is a great difference in the occurrence probability of pinholes between electromagnetic stirred continuous casting billets and those without electromagnetic stirring at the end. The oxygen and nitrogen in the molten steel exist in the form of a compound, and the molten steel rotates under the action of the mould electromagnetic stirring. The nitride and oxidized inclusions have the kinetic conditions of floating. Therefore, the inclusions of [O] and [N] float under the action of electromagnetic stirring.

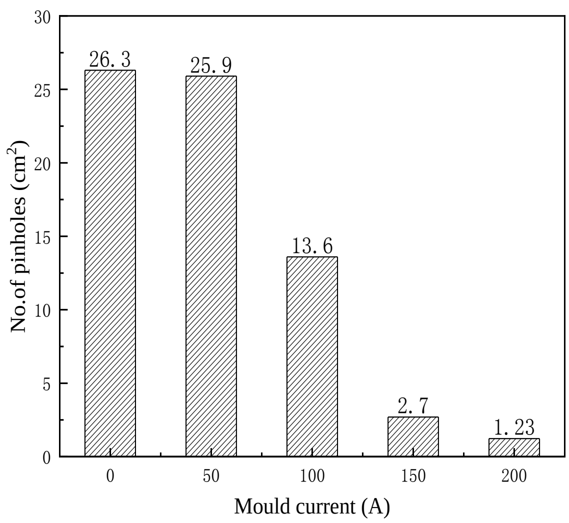

Figure3. *Effect of electromagnetic stirring on pinholes.*

Moreover, various inclusions in molten steel can be reduced by increasing intensity of electromagnetic stirring parameters. According to single factor tracking, inclusions can float within 3 minutes, and the inclusion removal rate becomes high, which shows that molten steel is relatively pure. During the pouring process, the electromagnetic stirring in the mould can promote the upward floating of the inclusions, thus purifying the molten steel and reducing the pinhole defects. The number of pinholes on the lower-fold surface of boron cold heading steel varies greatly with the increase of mould current as shown in Fig. 3. Strong current intensity can effectively reduce the number of pinholes. Under a single factor condition, the increase of current can reduce the pinhole ratio by 95.32%.

The content of oxygen and nitrogen in the cold heading steel billet were analyzed. **Table 1** shows the relationship between gas content and electromagnetic stirring current.

Table1. *Relationship between gas content and electromagnetic stirring current.*

Mould Electric Current (A)	O (ppm)	N (ppm)
0	28.9	54.5
50	28.4	53
100	26.5	51.3
150	25.6	50.4
300	22.2	50.1

It can be seen that the contents of [O] and [N] in molten steel decrease to different degrees with the increase of the mould current, indicating that electromagnetic stirring in the mould can remove the contents of [O] and [N] in molten steel. The removal capacity increases with the increase of stirring current. It can be seen from the low-magnification surface in **Figs. 4a and 4b,** that the number of pinholes was significantly more at stirring current of 150A than that of 300A.Under the condition of a single controlled variable, it is indicated that the stirring current of the mould has a significant reduction effect on the formation of the pinhole in the continuous casting billet.

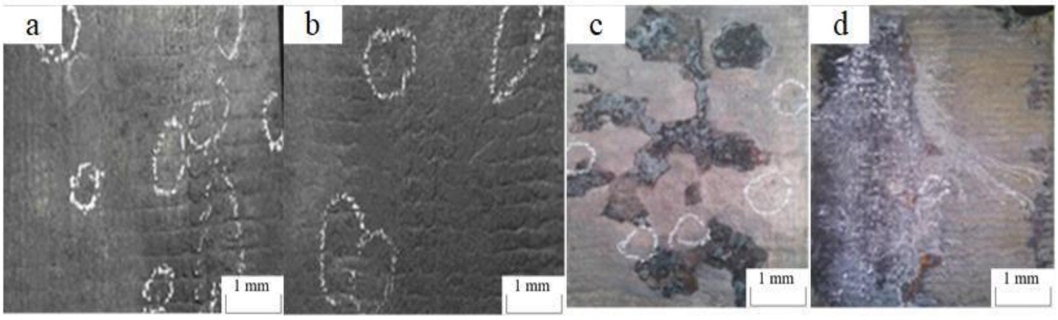

Figure4. *(a) The impact of 150A on the pinhole, (b) The impact of 300A on the pinhole, (c) The mould slag of rivet steel, and (d) The Stolberg mould slag.*

Effect of Protective Slag on Pinhole of Continuous Casting Billet

Through the same tundish, 6-7 flows for the mould slag of rivet steel, and 8-9 flows for Stolberg mould slag were used. The super heat, casting speed, and amount of molten steel were the same for both different mould slags. It can be seen that the gap between the two different mould slags and the pickling of pinholes on the sub-surface were more obvious. The mould slag of rivet steel has a higher surface adhesion with more studs and surface pinholes. No stuttering was found on the sub-surface of Stolberg mould slag, and only one pinhole was observed on the surface, as shown in Figs. 4c and 4d. Several experiments have been carried out on two different mould slags, showing that the number of pinholes in the Stolberg mould slag is less than that of the rivet steel slag. The average number of pinholes is reduced by 0.394 (/100 cm2),indicating that the Stolberg mould slag has superior performance in pinhole control as compared to the mould slag of rivet steel, and it also proved that the mould slag had great effect to the control the pinholes of continuous casting billet.

Analysis of Crack Defects in Continuous Casting Billet

Effect of Chemical Elements on the Surface Cracks

The harmful elements such as sulfur, phosphorus and aluminum in the steel have a great influence on the properties of the billet, which sometimes lead to increase the sensitivity of crack. The carbon content is 0.19-0.23%, avoiding the peritectic reaction zone, leads to a small probability of crack. The 100 pieces of billet with different phosphorus and sulfur contents were selected. It can be seen in **Table 2**that the crack ratio increases with the increase of phosphorus and sulfur content. It was found that phosphorus, sulfur and other chemical elements had a certain influence on the occurrence of cracks.

Table2. *The relationship between P and S elements and the crack ratio.*

No. of continuous casting billets	[P] %	[P]Crack ratio %	[S] %	[S]Crack ratio %
100	≤0.020	12	≤0.008	14
100	0.021-0.025	16	0.009-0.030	18
100	0.026-0.030	23	0.031-0.035	20

Effect of Stress on the Surface Cracks

If there is a large external force on the continuous casting billet in the secondary cooling zone, the billet may be cracked directly due to external deformation force, and the molten steel converted instantly into a continuous casting green shell in the mould. The improper mould oscillation parameters may produce friction force between the inner wall of the mould and the green shell. When the friction force reaches the casting strength of the billet, the primary green shell will form a small crack in the interior of the mould. After entering the secondary cooling zone, the small crack will further expand under the cooling condition to form a surface crack. According to field inspection, the base water frame is inclined, which leads to arc deviation of more than 5 mm, resulting in the increase of internal stress and cracks.

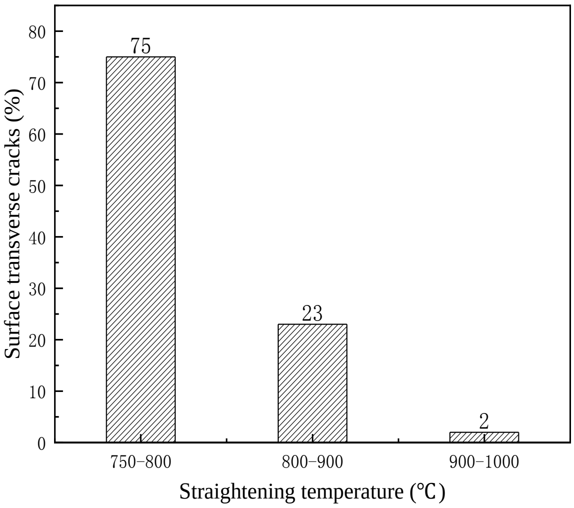

Figure5. *Relationship between straightening temperature and percentage of transverse crack.*

Effect of Temperature on the Surface Cracks

There is a gradient in the temperature distribution inside and on the surface of the billet, which leads to uneven cooling. Under certain conditions, cooling stress may be generated, and there is a relationship between the occurrence of steel cracks and the brittleness interval of continuous casting billet. During the casting of billet, the factors causing the crack are closely related to the mechanical properties at high temperature. According to the brittleness interval of steel grades, reasonable process and equipment parameters are selected to avoid the straightening interval, which can effectively reduce the crack of the continuous casting billet cracks by the straightening and temperature problems [11-12].In the middle of the last century, Childs in the United States started the experimental study of thermoplastic properties of continuous casting billets at high temperature. In the middle of this century, European IRSIDs, oral Gleeble, and others started to research on the high-temperature mechanical properties of continuous casting billets by the means of thermal simulation experiments. They concluded that continuous casting billet at 950-1350 ℃, had a large shrinkage section and good plasticity [13-15]. Statistics on the straightening temperature (see figure 5) show that when the straightening temperature is lower than 900 ℃, the occurrence probability of transverse cracks on the surface of continuous casting billet increases significantly.

Effect of Mould Slag Properties on the Surface Cracks

The field comparative experiments were conducted, and it was found that some of the slags had a slag ditch, and some adhered to the surface of the continuous casting billet, resulting of uneven cooling in the secondary cooling zone and surface cracks. It can be seen clearly from **Fig. 6** that un-melted mould slag particles are adhered on the surface of continuous casting billets with star-shaped cracks, indicating that the un-melted mould slag particles affect the secondary cooling effect, which leads to uneven cooling and appearance of surface cracks in the continuous casting billet.

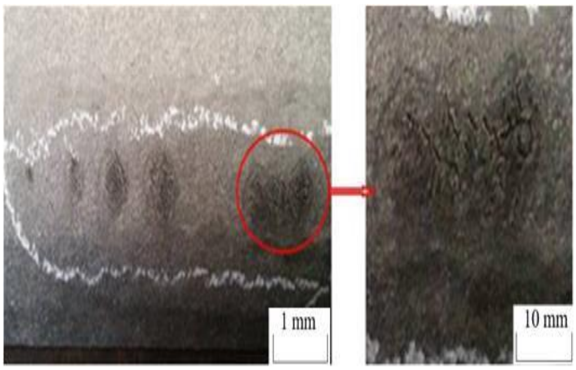

Figure6. *The crack caused by mould slag.*

Analysis of the Sub-Surface Cracks

Figure 7a shows the casting billet in the 1st and 10th secondary cooling zones during the production process of cold heading steel containing boron10B21.The cooling water was blocked due to the falling of the baffle, resulting in uneven cooling at the surface of the casting billet. The actual specific water quantity has a certain deviation from the preset specific water quantity. The EPMA-1720 electron probe was used to analyze the composition of the slag inclusions near the surface of No.1 and 2.

Through the detection of the cast billet, it was found that there were no inclusions as shown in **Fig. 7b,** but there were different morphologies, according to the scanning composition as shown in **Fig. 7c.**The crack morphology of the casting billet and the composition analysis of the crack were detected. The composition showed that there were no trace elements such as [Cu] and [Cr]. The [S] and [P] contents did not aggregate, and no inclusions were found. The phenomenon indicates that the crack of the casting billet is not at the meniscus of the mould, but there is a clear decarburization layer, indicating that the temperature at which the crack occurs in the casting billet is relatively high, and should appear in the first part of the secondary cooling zone. After the secondary cooling zone, the cracks continue to grow up.

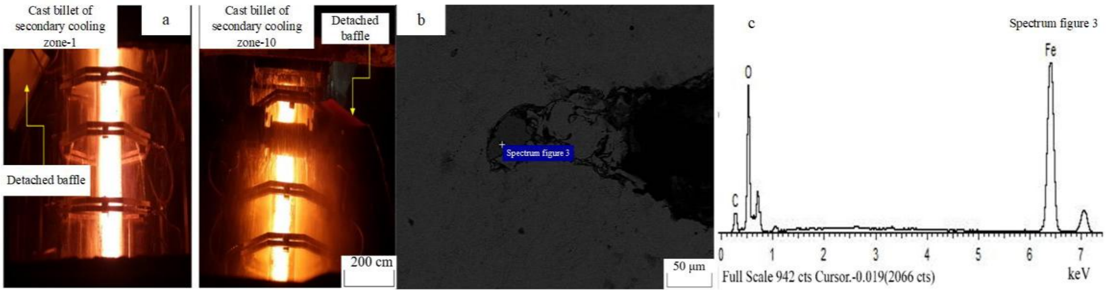

Figure7. *(a) Secondary cooling conditions during the production process of cold heading steel containing boron 10B21, (b) Inclusions morphology, and (c) Energy spectrum.*

Optimization Process and Its Effects

Estimation for the Improvement of Pinhole Defects

Increase the deoxidization intensity after the BOF process, then increase the [Al] content of the refining process from 0.005% to more than 0.045%. For the advance deoxidization, increase the inlet temperature to 1550-1570 ℃. The system of the furnace door was strictly implemented in the refining process. Optimize the mould electromagnetic stirring process parameters and replace the mould slag.

Estimation for the Improvement of Cracks in the Cast Billet

The [S] and [P] contents of molten steel were controlled below 0.005, and 0.020 respectively. In the straightening section, the billet was avoided to the brittle zone of low-temperature and purified the water quality of the secondary cooling zone. Meanwhile, the number of ladle casting furnaces was reduced up to or less than 18 heats, to avoid the blockage of the secondary cooling nozzle and other abnormal conditions.

Table3. *Statistics of 10B21 continuous casting billet defects.*

Process	Steel grade	Pinhole/%	Crack/%
Before optimization	10B21	42.3	10.8
Optimized	10B21	1	0.5

Optimize the Quality of Casting Billet and Cold Heading Performance of the Wire Rod

It can be seen from Table 3, that the defects of casting billets were greatly reduced before and after the optimization process, and the process rectification also improved the quality rate of rolling material. After optimization, pinholes were hardly seen on the surface of casting billets. The samples of 50 different billets were taken and only one billet was found to have one pinhole.

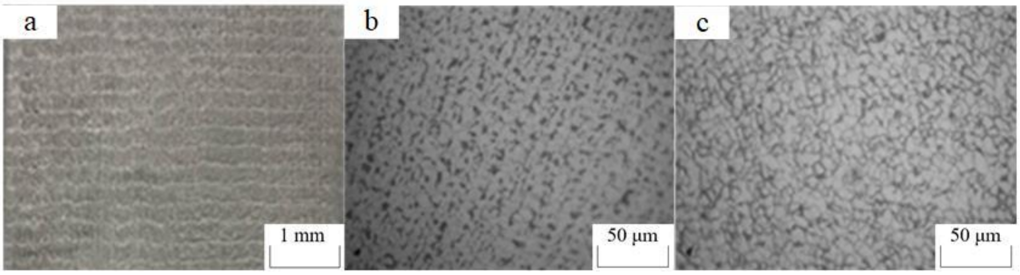

Figure8. *Surface morphology and low-magnification structure of continuous casting billet, (a) Optimized slab surface, (b) Picture of 00514 metallographic structures (×500), (c) Picture of 00516 metallographic structure (×500).*

The microstructure and grain size of 10B21 steel wire rod after optimization is shown in **Fig. 8.** It can be seen from the figure that the average grain size is above 8 grades, the crystal grains are fine, there is almost no decarburization layer, the metallographic microstructure is ferrite and pearlite, and the product has excellent internal quality. The performance experiments of 1/2 and 1/3 cold jacking by sampling the wire rod were carried out as shown in table 4. It was found that the quality rate of the wire rod has good results by cold forging experiment, and it was improved after the optimization process.

Table4. *Experimental results of cold forging performance.*

Batch No.	No. of Samples	1/2Cold Forging	1/3Cold Forging
00514	30	100%	100%
00515	30	100%	100%
00516	30	100%	100%

Conclusion

- An experimental study found that when steel (WT [O]+W [N]) > 80 PPM, pinholes increased significantly. The surface of casting billet has the number of pinholes especially in the adhesive area of the mould slag.
- When the content of [S] and [P] in the molten steel is high, the casting billet is in the brittle zone of low-temperature during the straightening section, abnormal conditions such as poor performance of protective slag, inclined cold water frame in the secondary cooling zone, and nozzle blockage lead to the increase of sub-surface cracks in the casting billet.
- Reducing the content of oxygen and nitrogen in the steel, improving the lubricity of the mould slag, and increasing the electromagnetic stirring current appropriately in the mould, are beneficial to reduce the pinhole defects on the surface of the casting billet.
- By decreasing the sulpher and phosphorus contents of molten steel as W[S] < 0.005%, W[P] < 0.020%,by reducing the number of continuous casting ladle furnaces up to or less than 18 heats, to avoid the billet from low-temperature straightening brittle zone in the straightening section, lead to reduce the crack defect of the billet.
- Through the above-mentioned optimization processes, the defects such as pinhole and surface crack of casting billet were effectively solved. Finally, the wire rod was uniformly organized with the grain size above the 8 grades, and the qualified rate of forging performance of 1/2 and 1/3 of the wire rod was 100%.

Acknowledgement

The successful completion of this project is benefited from the financial support provided by National Natural Science Foundation of China (U1760108, 51874001) and the Open Foundation of the State Key Laboratory of Refractory's and Metallurgy (G201711).

References

[1] Liu ZX. Cause analysis of crack formation in boron bearing cold heading steel SAE10B21. Metal Materials and Metallurgical Engineering 2018; 1: 14-18.

[2] Qian L. Research progress of cold heading steel at home and abroad. Journal of Rolling Steel 2000; 4: 25-29.

[3] He QJ. Factors affecting the quality of cold heading steel of xianggang. Journal of Iron and Steel 2003; 1: 25-28.

[4] Song W. Process optimization of smelting 10B21 Steel with100t BOF-LF-CC process. Journal of Special Steel 2015; 36: 17-20.

[5] Lu DX. Causes analysis of surface strain and internal crack in small section of casting billet. Journal of Continuous Casting 2006; 1(6): 26-27.

[6] Shi YJ, Qi CF, Li W. Discussion and practice of preventing CSP slab shrinkage. Journal of Hebei Metallurgy 2004; 5 (8): 14-16.

[7] Seiji I, HirokazuT, Tetsuo M et al. Control of early solidification in continuous casting by horizontal oscillation in synchronization with vertical oscillation of the mold. ISIJ Int. 1998; 50 (38): 461-468.

[8] Shuai XY. Cause analysis of cracking in cold heading steel containing boron 10B21. Journal of Steel Iron 2014; 6:42.

[9] Li JY. Cause analysis and improvement cracking of cold heading steel. China Metallurgy 2019; 29: 19-23.

[10] Zhang XR, Jiang T, Wang KZ et al. Production practice of boron bearing cold heading steel 10B21. Anhui Metallurgy 2017; 2: 55-59.

[11] Shi M, Liu YJ, Chen XM, Liu B et al. Cause analysis of cold heading cracking of 10B21 alloy cold heading steel wire rod. Journal of Shanxi Metallurgy 2018; 175 (5): 4-24.

[12] Zhang YJ, Zhang B, Zhang PC, Wang JH, Yu WJ, Han JT et al. Compression deformation at room temperature and inhomogeneous strain-hardening for medium carbon cold heading steel. Forging & Stamping Technology 2019; 44 (2): 168-172.

[13] Li YK, Chen MF, Li W, Wang Q, Wang YS, You Cet al. Characteristics and corrosion properties of alpha-Al_2O_3 coatings on 10B21 carbon steel by micro-arc oxidation. Surf. Coat. Technol 2019; 358: 637-645.

[14] Chen KJ,Hung FY,Lui TS, Tseng CH et al. Decrease in Hydrogen Embrittlement Susceptibility of 10B21 Screws by Bake Aging. *Metals 2016*; 6: 9.

[15] Yang CC, Wang ST: Improvement of Mechanical Properties of Spheroidized 10B21 Steel Coil Using Taguchi Method of Robust Design. Sensors and Materials 2018; 30: 503.

Citation: *Wei Zhang, Liqiang Zhang Ali Naqash Aonan Zhao, Chaojie Zhang, "The Control of Pinhole and Crack Defect on the Surface of Cold Heading Steel Billet", International Journal of Research Studies in Science, Engineering and Technology, vol. 6, no. 7, pp. 15-21. 2019.*